Eco-friendly Modification of Gulf Asphalt by Using Recycled Plastic Waste

BY

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Dedicated to my parents and all family members

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LIST OF ABBREVIATIONS

AASHTO	: American Association of State Highway and Transportation Officials
ANOVA	: Analysis of Variance
BAPCO	: The Bahrain Petroleum Company
cSBS	: Commercial Styrene-Butadiene - Styrene
cPB	: Commercial Polybilt
CBEM	: Cold Bitumen Emulsion Mixtures
CRM	: Crumb Rubber Modifier
CRT	: Crumb Rubber Tires
CSC	: Cyclic Shear Cooling
CRMA	: Crumb rubber modified asphalt
DMA	: Dynamic Mechanical Analysis
DSC	: Differential Scanning Calorimetry
DSR	: Dynamic Shear Rheometer
EVA	: Ethylene Vinyl Acetate
FHWA	: Federal Highway Administration, USA
FMS	: Florescent Microscopy Scanning
F-T	: Freeze Thaw
FT-IR	: Fourier Transform Infrared
F/T	: Freezing-and-Thawing
GPC	: Gel Permeation Chromatography
HDPE	: High Density Polyethylene
HL	: Hydrated Lime

HMA	: Hot Mix Asphalt
IRR	: Internal Rate of Return
ITS	: Indirect Tensile Strength
LDPE	: Low Density Polyethylene
LR	: Long Residue
MAPP	: Matrix Asphalt Pre-blending Process
MDPE	: Medium-Density Polyethylene
MDSC	: Modulated Differential Scanning Calorimetry
MMCM	: Measurement and Mapping of Crack Meander
MOT	: Ministry of Transportation
MPW	: Mixed Plastic Waste
MSCR	: Multiple Stress Creep Recovery
MWD	: Molecular Weight Distribution
OBT	: Optimum Blending Time
OMMT	: Organophilic Momtmorillomite
PAV	: Pressure Ageing Vessel
PB	: Polybilt
PE	: Polyethylene
PET	: Polyethylene Terephthalate
PG	: Performance Grade
PMA	: Polymer Modified Asphalt
PMB	: Polymer Modified Bitumen
PP	: Polypropylene

PPA	:	Poly-Phosphoric Acid
PPA	:	propane precipitated asphalt
PVC	:	Polyvinyl Chloride
rLDPE	:	Recycled Low Density Polyethylene
RHA	:	Rice Husk Ash
rHDPE	:	Recycled High Density Polyethylene
rPP	:	Recycled Polypropylene
RPW	:	Recycled Plastic Waste
RTFO	:	Rolling Thin Film Oven
RTR	:	Recycled Tyre Rubber
RV	:	Rotational Viscometer
SBR	:	Styrene-Butadiene Rubber
SBS	:	Styrene-Butadiene-Styrene
SEBS	:	Styrene-Ethylene/Butylene-Styrene
SEM	:	Scanning Electronic Microscope
SHRP	:	Strategic Highway Research Program
SIS	:	Styrene-Isoprene-Styrene
SMA	:	Stone Mastic Asphalt
SR	:	Short Residue
SWM	:	Solid Waste Management
UPG	:	Upper Performance Grade
VR	:	Vacuum Residue
WMA	:	Warm Mix Asphalts

WPE : Waste Polyethylene

WSA : Wood Sawdust Ash

WTE : Waste to Energy

ZSV : Zero shear Viscosity

ABSTRACT

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Utilization of Polymer-based product increased greatly in modern society and consequently these inert and hydrophobic materials become litter in the environment after their useful life and it causes adverse environmental impact by polluting agricultural land and fresh water. Although those plastic wastes are unsuitable for landfill disposal, some of the most developed societies dispose considerable amount of plastic wastes to landfill. In Kingdom of Saudi Arabia (KSA) rapid socio-economic development and fast industrialization resulted in tremendous waste generation. Most recent estimate claims that Saudi Arabia produced 27 million tons of wastes per year with a generation rate of 1.4 Kg/ capita/ day. Almost 10% of them are plastic wastes. This research explored utilization of plastic waste to modify local asphalt.

Saudi Arabia has a wide spread Airport & highway pavement network and each year new projects are adding to the network. The extremely hot climate is causing permanent deformation and variation of temperature between winter and summer, days and night is also causing thermal cracks. This, in addition to increased traffic loading demand for improved road material characteristics. Every year ministry of transport (MOT) and other agencies are spending money to procure asphalt modifiers such as polymers, hydrocarbons, chemicals. No endeavour was done to explore the utilization of locally available recycled plastic material. Laboratory experiments of this study prove that recycled low-density polyethylene (rLDPE), high density polyethylene (rHDPE) & polypropylene (rPP) added with little amount of commercial Styrene-Butadiene-Styrene (cSBS) widen the temperature susceptible range of local asphalt from 64°C to 70 °C, 76 °C and even up to 82°C. The dynamic shear rheometer (DSR) result demonstrate that rHDPE, rLDPE and rPP modified bitumen significantly improve the rutting resistance at high temperature. To achieve the targeted upper performance grade (UPG) of base asphalt of 76°C and 82°C twelve most promising blends were identified. Comparative cost analysis revealed that road agencies can save 58 to 90% of cost using this modifier instead of the conventional one.

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ملخص الرسالة

الاسم الكامل : محمد أحسن حبيب

عنوان الرسالة : تحسين أداء الاسفلت العربي باستخدام المواد البلاستيكية المعاد تدويرها.

التخصص : الهندسة المدنية

تاريخ التخرج : نوفمبر 2015

إن استخدام المنتجات المصنعة من البوليمر تزداد بشكل كبير في المجتمع الحديث، وبالتالي فان هذه المواد الخاملة الغير قابلة للتحلل أصبحت تتراكم على شكل نفايات في البيئة المحيطة بعد الانتهاء من استخدامها؛ ويسبب ذلك أضرار بيئية تؤدي الى تلوث الأراضي الزراعية والمياه العذبة. وعلى الرغم من أن مكب النفايات هو مكان غير مناسب للتخلص من تلك النفايات البلاستيكية, الا أن أكثر المجتمعات تقدما تقوم بالتخلص منها بكميات كبيرة في مكب النفايات. ولقد أدت التنمية الاجتماعية والاقتصادية السريعة والتصنيع المتسارع في المملكة العربية السعودية الى انتاج النفايات بكميات هائلة. فتشير معظم التقديرات الحالية أن المملكة العربية السعودية تنتج 27 مليون طن في السنة الواحدة بمعدل 1.4 كجم للفرد الواحد في اليوم الواحد حيث أنه حوالي 10% من جملة هذا الانتاج عبارة عن نفايات بلاستيكية.

تمتلك المملكة العربية السعودية شبكة من الطرق والمطارات واسعة الانتشار وكل عام تضيف مشاريع جديدة على الشبكة. يؤدي المناخ شديد الحرارة لحدوث تشوهات دائمة في الطرق، كما إن اختلاف درجات الحرارة بين فصلي الصيف والشتاء و بين ساعات النهار والليل وبالإضافة إلى زيادة الحركة المرورية يتسبب بحدوث التشققات. لذلك يتوجب تحسين خصائص مواد الطرق. تقوم وزارة النقل في المملكة بانفاق المال لاستيراد مواد تحسين الاسفلت مثل البوليمرات والمواد الهيدروكربونية، والمواد الكيميائية. ولم يتم حتى الان إنجاز اي دراسة لاستكشاف استخدام المواد البلاستيكية المتاحة محليا والمعاد تدويرها.

تشير نتائج التجارب العملية في هذا البحث أنه عند اضافة البولي ايثيلين منخفض الكثافة المعاد تدويره (rLDPE)، والبولي إيثيلين عالي الكثافة (rHDPE) والبولي بروبلين (rPP) الى كمية قليلة من الستايرين البيوتادبين الستايرين (cSBS) فانه يزيد مدى تحمل الاسفلت المحلي لدرجات حرارة عالية من 64° إلى 70° ، 76° وقد تصل إلى 82 درجة مئوية. كما تشير نتائج اختبارات أداء الاسفلت المحسن بهذه المواد انه يوجد تحسن في مقاومة التخدد عند درجات حرارة عالية. ولتحقيق الجودة المستهدفة لاداء الأسفلت عند درجات الحرارة العالية فانه تم دراسة اثني عشرتركيبة من المواد المعاد تدويرها بنسب مختلفة. المقارنة بين تكاليف الأسلوب المحسن والأساليب التقليدية كشف عن توفير حوالي 58-90٪ من اجمالي التكلفة لوكالات الطرق عند إستخدام هذا التحسين بدلا من الاساليب التقليلدية.

ماجستير العلوم

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CHAPTER 1

INTRODUCTION

1.1 Background

As the level of industrial packaging is growing within the Kingdom of Saudi Arabia, the amount of solid plastic waste from packing material like plastic bottle and similar utilities are continuously increasing. This leads to difficulties and increased cost related to solid waste management. Most of the plastic wastes cannot be decomposed after landfill disposal, which have unfavourable effects on the environment. Rapid industrialization and fast urbanization in Saudi Arabia have resulted in tremendous waste generation and thus solid waste management (SWM) is becoming a great challenge for the government & local bodies. Most recent estimate claims that Saudi Arabia produced 27 million tons per year with a generation rate of 1.4 Kg/ capita/ day (Omar K. M. Ouda et al., 2013) almost 10% of them are plastic waste. It was found that, plastic waste constitute about 10% of total generated solid waste according to literature survey of the solid waste composition statistics of several developed countries (Casey, et al. 2008). Solid waste generation in the 3 largest cities Dammam, Jeddah and Riyadh surpasses 6 million tons per year which gives a warning of the enormity of the problem.

On the other hand asphalt pavements require huge amount of construction materials. Due to the notable binding and waterproofing properties of asphalt, it is used primarily in construction of flexible highway and airport pavement and as a major component in roofing materials. The behaviour of asphalt cement in service is dictated by its inherent properties and by the mechanical and environmental conditions to which it are subjected. The asphalt available in Saudi Arabia can be used without modification, if the maximum pavement temperature at service condition remains below 64°C. But it has been found that average maximum consecutive seven day temperature on pavement of the country ranges from 64°C to 76°C. There are three zones Saudi Arabia in terms of average maximum consecutive seven-day pavement temperature, minimum pavement temperature, and temperature susceptibility of the asphalt. It indicated that locally produced bitumen satisfies the environmental condition of region like Riyadh only, but for Eastern province, PG -76-10 asphalt and for other western region, PG-70-10 asphalt are needed (Abdul Wahhab, et al.,1997).

Additionally, the increase in overloading of trucks & the significant variation of seasonal & daily temperature demand improved material characteristics. Under these circumstances, it is essential to modify the asphalt binder using suitable modifiers to improve its initial engineering properties.

1.2 Discussion of the Problem

This research work focuses utilization of locally generated plastic waste to ease problems with plastic waste management and their environmental consequence at the same time to meet up modification requirement by the growing paving industries. Following subsections describe them.

1.2.1 Polymer Waste Scenario and Environmental Consequence

Due to the diversified application and technical advantages, polymer-based product becomes popular in modern society. Subsequently this increased usages of polymer brought some disadvantages while people discard them after their useful life and those acted as litter in the environment.

These waste polymer /plastic are inert and hydrophobic material (Scott, 2000) which causes adverse environmental consequences by polluting agricultural land and fresh water (Thompson, Moore, Yom Saal, & Swan, 2009). In marine environment in a form of debris, it creates aesthetical problems and hazard to fishing & tourism (Moore 2008; Gregory 1978). The effect to the wildlife is enormous, it has been well documented that more than two hundred and sixty species of invertebrates, fish, turtles, birds & mammals were found to ingest or become tangled in debris of plastic, causing reduction of movement & feeding, reduced reproductive output, ulcers & death (Laist 1997; Derraik 2002; Gregory 2009). This plastic debris ingestion even can transmit toxic substances to food chain (Teuten et al. 2009)

In spite of having awareness current world even most developed societies dispose considerable amount of plastic wastes to landfill (Thompson et al., 2009). Some waste plastics are used to recover some energy using incineration technique. Although this waste-to-energy (WTE) initiative process has some more benefit than landfill disposal, it will not decrease the demand for raw material to be used in plastic production. However this option is questionable as there is a concern of emission of carbon di oxide (Katami et al. 2002; Scott, 2000). Due to this ecological limitation incineration process is less efficient than recycling or reusing. The following diagram (Figure 1.1) illustrates global plastic waste circulation and utilization scenario for the most of countries. Outlet-1 is the worst practices which causes enormous environmental consequences, landfilling is also not suitable technique rather it is the losses of resources. Incineration is better than

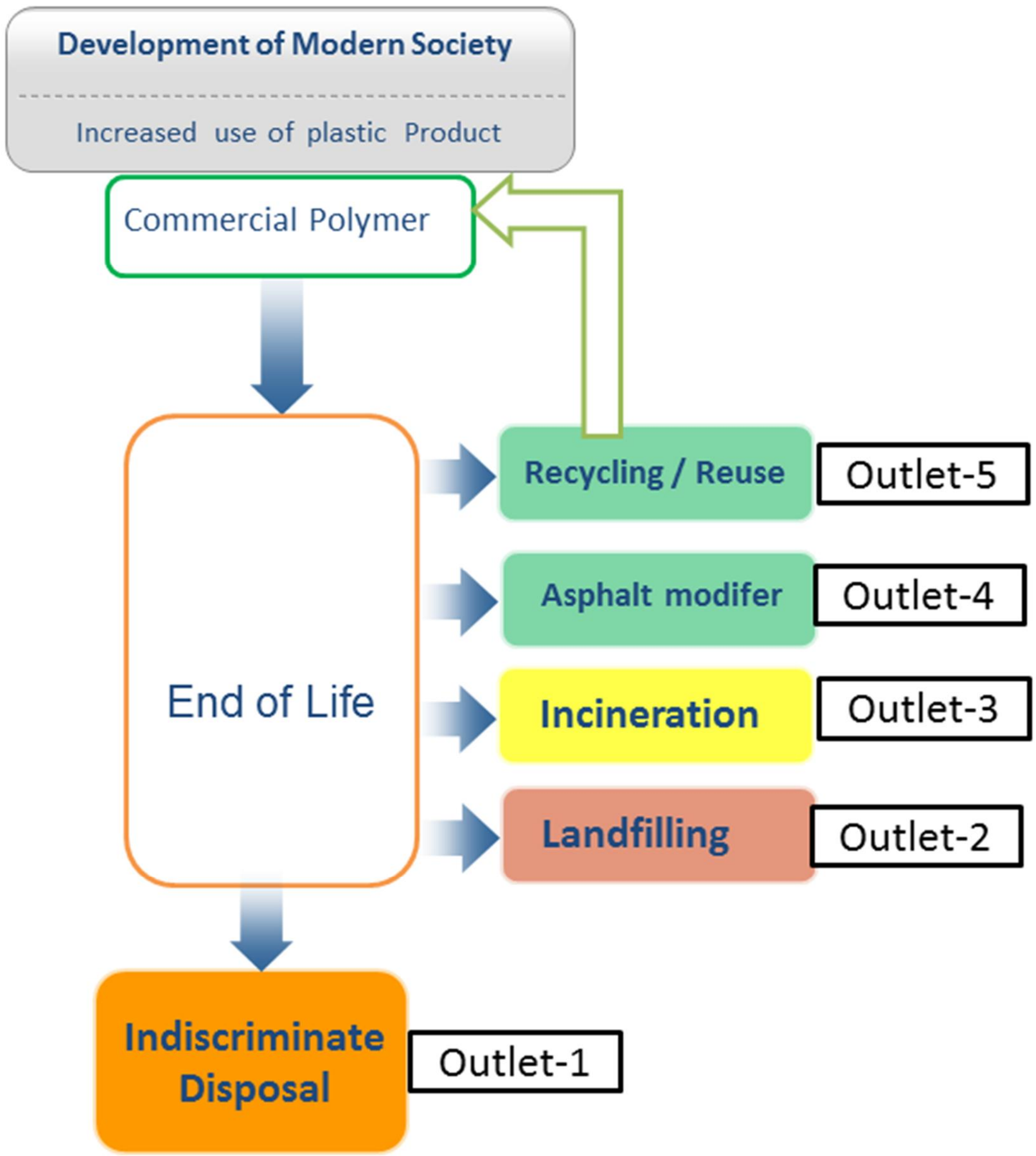


Figure 1.1: Plastic waste utilization Diagram

landfilling but it is questionable due to emission of greenhouse gasses recycling or reusing technique in outlet -5 is a good practice but not suitable for all the plastic waste because some polymeric chains in polymer prevent to reshape after moulded. So recycling technique cannot solve problems associated with plastic waste.

Therefore plastic waste used as modifier of asphalt can be a good solution to get rid of plastic waste, at the same time saving costly commercial material by avoiding use of conventional commercial polymer.

In Kingdom of Saudi Arabia (KSA) rapid socio-economic development and fast industrialization resulted in tremendous waste generation. Most recent estimate claims that Saudi Arabia produced 27 million tons per year with a generation rate of 1.4 Kg/ capita/ day (Omar K. M. Ouda et al., 2013) almost 10% of them are plastic waste. There is enormous gap between the generation and the recycling rate. Only about 10-15% of total waste of KSA are recycled (Zafar S., 2015), rest of them goes to land fill. These ever growing unwanted plastics not only creates environmental problems but also wastes money for the SWM. In 2011 KSA allocated 29 billion SAR to manage municipal solid waste. Additionally these non-disposable and hydrophobic wastes are mostly responsible to reach the capacity of landfill.

1.2.2 Paving Industries & Demand for Modification in KSA

Saudi Arabia has a wide spread airport & highway pavement network and each year new branches are adding with the network. These roads were built with good standard but due to adverse environment and high traffic distresses are often found in those roads. The extremely hot climate is causing permanent deformation on the other hand variation of temperature between winter and summer, days and night also causing thermal cracks.

Government invested billions of riyals to build those roads to facilitate people's movement and for the development. The asphalt available in Saudi Arabia can be used without modification, if the maximum pavement temperature at service condition remains below 64°C. But it has been found that average maximum consecutive seven day temperature of pavement of the country ranges from 64°C to 76°C and based on that, Saudi Arabia were divided in three major regions. It indicated that locally produced bitumen satisfies the environmental condition of region like Riyadh only, but for Eastern province, PG -76-10 asphalt and for other western region, PG-70-10 asphalt are needed (Abdul Wahhab et al.,1997).

Additionally, the increase in over loading of trucks and the significant variation in daily & seasonal temperature demand improved material. Under these circumstances, it is essential to modify the asphalt using suitable modifiers to improve its initial engineering properties.

Asphalt modification have been used in several developed countries successfully, and it has been observed that pavement having modified asphalt perform better resistance to address thermal cracking, rutting, fatigue, stripping & temperature susceptibility (Sangita, et al., 2011; Baghaee, et al., 2012).

Commercial Polymer has been popularly utilizing for the modification of asphalt to increase internal properties and temperature susceptible range. However high cost of polymer modified binder (PMB) has been described as one of the major challenges in asphalt paving industry (Bowering 1984), (Zhu, Birgisson, & Kringos, 2014). Additionally this use of commercial polymer will definitely create pressure on demanding polymer market.

With this concern of reducing consumption of commercial polymer and at the same time utilizing recycled plastic waste for the modification of asphalt for the sustainable development was key objective of current research.

Every year MOT and other agencies are spending money to procure modifier such as polymer, hydrocarbon, and chemicals. No endeavour was done to explore the utilization of locally available recycled material. This study has investigated the suitability and possibilities of utilization of the potential recycle plastic waste.

It will definitely act like striking two birds with a single stone: the environmental management problems of RPW will be minimized, and the initial engineering properties of the asphalt eco-friendly ways also will reduce the construction and maintenance cost of local highways.

1.3 Research Objectives

The Main objectives of the research are summarized below:

- To evaluate the rheological properties of modified asphalt binders prepared by blending different potential RPW in combination with virgin polymer with bitumen at different ratios in comparison with plain asphalts.
- To obtain optimum content of RPW and RPW combination with virgin polymers (elastomer and plastomer) to improve the performance grade (PG) of asphalt so that modified asphalt can be used up to maximum service temperature of 76 and 82°C.

- To explore eco-friendly modifier which will add value to locally produced asphalt of Saudi Arabia

CHAPTER 2

LITERATURE REVIEW

In some of the encountered past literatures which explores the recycled polymer waste modification of asphalt binder, the optimized polymer-asphalt mixing duration was reported to be above 2 hours at temperatures of 180°C to 200°C (Casey, et al. 2008). When asphalt is subject to high temperature for a long period of time like 2 hours, it will definitely undergo oxidation (Fang, et al. 2009). Oxidation is responsible for deterioration of certain mechanical properties of the asphalt due to aging and the associated energy cost will be tremendous when this proposed blending method is to be adopted for a large scale construction project.

Some of the contemporary and important research work addressing the asphalt binder modification for improved performance in road and other application like roofing has been discussed.

2.1 Polymer Modified Asphalt

2.1.1 SBS Modified Asphalt

Murphy et al. (Murphy, et al., 2000) used various polymers involving polyethylene (PE), polypropylene (PP), ethylene vinyl acetate (EVA), styrene butadiene styrene(SBS), polyether polyurethane, truck tyre rubber and ground rubber as an asphalt modifier with the intention of finding an appropriate blend which will ensure similar properties of the Polyflex 75 (modified binder) and 100 penetration bitumen. Their experimental result shows blends with LDPE (Low density polyethylene) and EVA are good for further consideration because of their similar properties to that of 100 penetration bitumen and Polyflex 75.

Zhu et al. (2014) presented the overview of advantages and disadvantages of polymer modification of asphalt for road construction over the last forty years. They discussed several widespread plastomers & elastomers in asphalt modification considering their merits & demerits, including PE, PP, EVA, ethylene-butyl acrylate (EBA) & SBS. They cost of polymer is one of chalange in field of PMB.

Dong et al. (2014) used four SBS with different Styrene–butadiene ratio, which are SBS 1201, 1301, 1401 & 4303 with the Styrene–butadiene ratio 20/80, 30/70, 40/60 & 30/70 respectively. Among these four first three are linear SBS and the rest one is radial. They found significant changes of dispersion of SBS in modified asphalt as SBS polymer content increases at temperature 175^{o}C with mixing with speed 3000 rpm for 60 minutes duration. However they also found that high dispersion does not always reflect the continuous polymer phase.

Li et al. (2012) studied the influence of SBS on stability of asphalt mix at high temperature. Using all conventional testes they found 5% to 6% SBS modifier as optimum amount. Their findings also suggest that stability of mixtures at high temperature was mostly affected by the softening point of styrene-butadiene-styrene (SBS) modifier.

SBS & asphalt binder has various chemical molecular structures and the physical and chemical reaction between them is complicated. Geng et al. (2014) studied reaction pattern of the SBS with asphalt by observing molecular changes through gel permeation chromatography (GPC) analysis of modified bitumen at initial preparation stages (before and after the RTFO test) and in service life (before and after the PAV test). They found crosslink of SBS to be the prime reaction in SBS. The slight degradation of molecular weight after RTFO and significant degradation of that was observed after PAV thus reducing the capability of modifying the performance of asphalt binder after aging. Al-Hadidy and Tan (2009) used starch and SBS to improve the asphalt in this study. They applied mechanistic-empirical design approach to observe the improvement. Their findings suggested the improvement of asphalt mix in terms of moisture damage and temperature susceptibility. The outcomes also demonstrated that starch modifier is useful as anti-stripping factor& it can reduce energy consumption by 30% moreover starch shows resistant to fuels and some chemicals and solvents.

Using Fourier Transform Infrared (FTIR) spectroscopy Ouyang et al. (2006) evaluated aging properties of base asphalt and SBS modified asphalt. They utilized some anti-oxidant zinc di-alkyldi-thio-phosphate (ZDDP), zinc di-butyl di-thio-carbamate (ZDBC)/naphthenoid oil. Antioxidants, ZDDP/ZDBC modified polymer modified asphalt are impenetrable to the formation of carbonyl to several area, locating the improvement of aging resistance of the polymer modified asphalt (PMA) by the addition of the antioxidants.

Vlachovicova et al. (2007) utilized different amounts of radial styrene–butadiene–styrene (SBS) copolymer and conducted a comparative study between evaluated ZSV (zero-shear viscosity) from the creep-recovery curve and instantly estimated ZSV. At higher stress level they observed time-dependent microstructure of SBS-modified asphalt. This behaviour was outside the usual linear viscoelastic range.

Ozen (2011) used hydrated lime and SBS as a modifier and found addition of lime with SBS to be beneficial in terms of rutting resistance. His experimental results showed that SBS mixtures display best performance according to the other mixtures types.

Yilmaz and Çelog˘lu (2013) conducted a study using 3.8% SBS as a modifier of pure bitumen of grade PG 58-34. Their blending temperature was 180°C and they blended for the 60 minutes at a speed of 1000 rpm. They found the improvement of Performance Grade (PG) up to PG 70-34. The improvement in terms of stiffness, stability, tensile strength & resistance to fatigue and permanent distortion are also noticeable.

Zhang and Hu (2013) used styrene-butadiene-styrene (SBS) & styrene-butadiene rubber (SBR) with the addition of poly-phosphoric acid (PPA) or sulphur. Their blending temperature was 180°C however the blending speed was higher (4000rpm) and they sheared for 40 minutes and stirred for further 120 minutes at same temperature and sped. They considered good storage solidity& high softening point before & after ageing as a qualification criteria. For measuring storage stability of modified asphalt they used a 32mm diameter aluminium tube with a height of 160mm. After filling and sealing the tube, it was kept at oven at 163°C for 48 h. Then softening point from top and bottom portion was determined. If the difference of softening point was less than 2.5°C, then it was considered to have good high temperature storage stability. Their findings suggest that addition of poly-phosphoric acid with SBS/SBR can improve the high-temperature performance but it reduces the storage stability of the asphalt on the other hand Sulphur can enhance both the storage solidity& higher temperature performance.

Jasso et al. (2010) added montmorillonite/ organo - montmorillonite along with SBS for the modification of asphalt. The result showed that addition of 3% organo – montmorillonite with SBS can give more viscoelastic properties than the asphalt modified with only SBS.

Kök et al. (2014) conducted their study to evaluate the effect of SBS and Sasobit used both separately and common in the same mixture. As it is known that SBS increase the viscosity and Sasobit reduces it, goal of their study was to determine how the binder properties are affected by the common usage of these additives. The outcomes of the experiment exhibited that the characteristics of the bitumen modified with combined additives were remarkably different from that of individually modified bitumen.

Aflaki and Tabatabaee (2009) worked for the Iran by conducting experiment to determine PG grade of asphalt produced from seven production plant and comparing them with the required PG for the 13 various climatic region. They also utilized some potential modifier viz. SBS, Crumb Rubber, Poly-phosphoric acid, gilsonite and air blowing. Among 13 required performance grades only four can be fulfilled by utilizing fresh binder. They have also found that their selected modifier can fulfil rest of the PG requirement.

Alatas and Yilmaz examined in their research rheological & mechanical characteristics of bituminous binders by several polymeric modifiers, Kraton D1101, Kraton MD243 &Evatane@2805. They used two distinct SBS (SBS D1101& developed SBS MD243) &EVA (Evatane@2805) for bitumen modification. Ultimately they demonstrated that all polymers enhanced the Marshall stability & stiffness of mixtures and resistance to moisture damage& fatigue cracks. Meantime, with utilizing MD243, recent SBS additives, mixtures with lower viscosity values were observed.

2.1.2 Poly-Ethylene Modified Asphalt

Singh et al. conducted research on modification of asphalt by using maleic anhydride and recycled low-density polyethylene (LDPE) (Singh, et al. 2013). They found significant raise in the softening point and some reduction in the penetration due to modification with maleic anhydride. The difference was conspicuous when the virgin asphalt was modified with higher dosages of maleic anhydride. The viscosity of this asphalt was found more than the asphalt in short of maleic anhydride thus raising visco-elastic performance of the resulting blend. The recoverable blends composed of recycled LDPE and SBS displayed satisfactory softening point and low temperature susceptibility.

In a comparative analysis of modifying effect of reactive and non-reactive polymer (Navarro, et al. 2009), the effect of recycled EVA and a combination of recycled EVA with LDPE (EVA/LDPE) on the rheology of asphalt was reported. The recycled EVA and EVA/LDPE modified asphalt shows both increased loss and elastic modulus. Bitumen modified with 5% EVA/LDPE yields the maximum linear viscoelastic moduli within -10°C and 50°C temperature range.

Toraldo et al. (2014) used EVA and LDPE at different dosages (3%, 6% and 9%) to modify the bitumen in Italian environment and studied their added benefit in the mixture in comparison with the unmodified mix. They also conducted comparison of different dosages in terms of their performance. They found improved fatigue life and rutting resistance at the increase of dosages for both the polymer only exception for 3% LDPE, at which they found reduction of rut resistance in comparison with the fresh bitumen.

Al-Dubabe et al. (1998) conducted extensive research for the modification of the gulf asphalt by using different polymers (LDPE, HDPE, polystyrene, SBS, Crumb rubber and polybelt) of different grade. Based on rheological properties, storage stability and cost effectiveness potential modifier was determined. Polypropylene (grade 500U), LDPE (Grade 1182), SBS and Crumb rubber tires were selected as favorable polymers. 3% of SBS or 10 % of crumb rubber tires were found to be most promising for asphalt source of Ras Tamura refinery of Saudi Arabia. For Riyadh asphalt 3% LDPE (grade 1182) or 10% Crumb rubber tires or 1.5% polypropylene (grade 500U) were found most favorable. For the asphalt of BAPCO refinery, Bahrain, the most suitable modifier were 1.5% polypropylene (grade 500U) or 3% of SBS. For asphalt from AI-Ahmadi refinery, Kuwait: 3% LDPE (Grade 1182) concentration of and 5% crumb rubber tires (CRT) and 1.5% Polypropylene (grade 500U) were found to be most favorable.

The micro-structure and properties of asphalt modified with polyethylene (PE) waste was investigated (Fang, Yu et al. 2012). The homogeneity and dispersion of the PE waste in the bitumen was improved by the addition of an organophilic Momtmorillomite (OMMT). The PE waste was collected from domestic garbage. FT-IR result shows no change in functional group of the modified asphalt, and SEM and fluorescence microscopy analysis shows more homogenous micro-structure due to the OMMT addition. And as a result, an increased softening point, penetration with improved ductility.

Punith and Veeraragavan (Punith and Veeraragavan 2011) used low-density polyethylene collected from domestic waste, which was shredded to 2mmX2mm. 5% of the waste was mixed with the binder at 165°C with 3,500 rpm shear mixer. The similarity of the polyethylene-modified binder was checked by FMS (florescent microscopy scanning). They examine three factors: (a) impact of temperature on binder characteristics, (b) impact mixing time on binder characteristics & (c) impact of PE Content on binder characteristics. They found minimal change in softening point and penetration values with the increasing temperature of blending. It is feasible that a higher temperature enables better mixing of the polyethylene, so growing the stiffening impact of the polymer on binder. Outcomes of the experiment revealed that if PE content increase in percentage then ductility and penetration values decreases and in addition an increment in softening point temperature was remarked. As the PE content increased the penetration & the softening points smoothly reduce. They showed that by sustaining blending period stable, the increasing content of PE needed high temperatures. They found that the loss due to heating in the case of PE-modified asphalt is not more than that of neat asphalt.

Fang, C. et al. adopted combined modification of asphalt using packaging polyethylene and rubber powder (Fang, et al. 2013). They performed rotating film oven (RTFO) test and studied the aging mechanism using the Fourier Transform Infra-red Spectroscopy (FTIR). They used rubber powder of 300-600nm fineness range & waste polyethylene of 1.5cm X 2.5cm chip size. The polymer -asphalt blending was performed at 180°C temperature, at four different combination and percentages. A remarkable decreasing in the ductility & some amplifying in the softening point was observed after RTFO aging test. However, results indicate that change in the ductility and softening point of modified binder due to aging of the binder to be less important than that of base asphalt. The penetration variation of modified asphalt is also smaller than that of raw bitumen, which is an indication of non- dependency of the penetration on the aging of modified asphalt, to some extent.

Fang et al. (2014), conducted their experiment to find the optimum mixing parameter to ensure the maximum storage stability of the modified bitumen. Their selected modifier was waste PE (recycled milk bag) and they found optimum shear rate, blending temperature and blending time respectively 3750rpm, 150^{o}C and 90 minutes. They found the blending time as the dominant player to confirm the miscibility/dispersion. The fluorescence micrographs clearly showed that at increasing blending time polymer is cut to increasingly finer pieces up to 200 micro m @ 90 minutes but when the blending time reached 120 minutes polymer agglomeration occurs.

Fang et al. (2014) organized a research work to utilize the waste plastic packaging films to modify asphalt. Instead of regular polymer they took into account the recycled packaging-waste polyethylene (WPE) as a modifier in their studies with paving bitumen, & the pavement features of the modified asphalt are studied. They stated that after mmodification with WPE, the softening point of asphalt increased and the penetration and temperature susceptibility reduces. They also showed that the modification of asphalt gives a new path to recycle polymers that can enhance the pavement characteristics of the asphalt mixing & cut the expenses along with reducing the white pollution due to packaging-waste polymer (WPE).

Fang et al. (2013) used Waste polyethylene packaging (WPE) to modify asphalt, & studied the hot storage stability of the modified bitumen and discussed the mechanism of the storage stability at hot condition of WPE modified bitumen. Their experimental results proved that the modification of bitumen with waste polyethylene packaging was a physical procedure. They also emphasized that when the performance of modified bitumen will be better if the PE content is less than 10 wt % in bitumen matrix.

Fang et al. (2008) conducted a research to increase the performance of base asphalt, effectual elevate the attribute of pavement, lengthen the maintenance time & lifetime of highway and decrease the costs of conservation. They adopted the retrieved packing polymer to improve the ordinary road asphalt. The results of their research showed that the softening point and the freeze-to-crack temperature reduced after improvement and the apprehensive performance of base asphalt developed remarkably. Their infrared treatment recommended that waste-polyethylene (WPE) in packaging combines the matrix of asphalt within physical mixture moderation.

Kim et al. (2004) made a comparison between linear scission model and developed topological scission model in methodical way. They established a noticeable difference in MWD (molecular weight distribution) between linear scission (yielding a bimodality) & topological scission (leading to a long tail in MWD). Additionally, they studied mechanical scission that would happen in stirred autoclave reactors owing to mechanical reaction. Besides they explored the molecular mechanism of LDPE in relation with the scission kinetics & the topological scission model.

2.1.3 Different Waste Plastic/ Waste Modified Asphalt

Fang et al. (2013) prepared waste packaging polyethylene or organic montmorillonite nano composites & employed as an asphalt-modifying factor. They evaluated the formation & morphology of the nano composites and the impacts of organic montmorillonite nano composites (OMMT) on the thermal characteristics of waste packaging polyethylene (WPE). They also studied the microcosmic impacts& physical characteristics of the compound factors on the raw asphalt. They showed that WPE/OMMT asphalt-modifying factor were exfoliated nano composites. They also showed that nano composite bitumen-modifying factors do not influence higher temperature characteristics of the polymer modified-bitumen however accurate this scarcity at lower temperature.

Fang et al. (2014) conducted a research to find the application of waste plastic packaging films for modifying asphalt. The recycled packaging-waste PE (WPE), in lieu of usual commercial polymer, was taken into account as a modifier in laboratory with paving asphalt, & the pavement features of the modified asphalt were examined in their research. Their key findings can be described as follows-(i) The properties of the asphalt are improved (ii) The low-temperature anti-cracking & the anti-rutting, anti-fatigue, and anti-water features also are developed after modification and (iii) It can enhance the pavement characteristics of asphalt along with rescue wealth & lessen white pollution.

Ho Susanna et al. performed asphalt modification using compositions of 3 commercial LDPE materials & three recycled low-density polyethylene materials (Ho, Church et al. 2006). They found significant contribution of weight of polymer molecule and distribution of that molecular weight of recycled LDPE in modified asphalt in terms of low temperature behaviour and hot storage stability. Thus they claimed that the LDPE with low molecular weight & wide molecular weight distribution are more acceptable than higher molecular weight & narrower molecular weight distribution polymers.

The feasibility and potential use of recycled waste polymer as modifier for stone mastic asphalt (SMA) in Ireland was investigated (Casey, et al. 2008). The study was aim at boosting the market value of the commercially available local recycled waste plastic, and proving a guideline and insight to the use of the recycled waste polymer (RPW) for quality road construction in the country. Several types of RPW were identified, namely: low density polyethylene (LDPE), medium density polyethylene (MDPE) & high (HDPE), mostly utilized for packaging & plastic bottling; polyvinyl chloride (PVC), polypropylene (PP), polyethylene terephthalate (PET), & acrylonitrile butadiene styrene (ABS). Only three of the RWP (PP, HDPE & LDPE) were successfully blended with the binder. The remaining polymers were found immiscible with the bitumen due to their high melting point, high density or low surface area of the processed RPW. A straight grade bitumen was selected for the study. The optimized bending time and temperature are 2 hour 30 minutes and 180°C at 4% HDPE loading, which is the RPW blend that shows the most promising results. The RPW were found to outperform the traditional mix when regard to performance testing like as wheel track & indirect tensile fatigue tests. But the virgin polymer still yields better results than the RPW. The work recommends the blending of both RPW and virgin polymers, especially the elastomeric type, so as to compensate for the loss of elasticity of the RPW modified asphalt. As with most similar studies, the mixing time of the RPW is long and could be very costly when large quantity of bitumen is needed for road project. And the morphology of the binder has not being closely examined to determine the extent to which the RPW blended. This could be done with high resolution imaging such as scanning electron microscopy etc. The above mention point is important when it comes to analyzing the effect of time, temperature and rate of shearing (which has not been mentioned) on the morphology. So, for all that is observed, the increase penetration and softening point of the binder could be mainly due the oxidation of the binder as a result of prolong mixing time, not because of the homogeneous mixing of the RPW with the binder.

The effect of a hydrogen-peroxide-treated (ozonized) PVC pipe waste on the behaviour of asphalt mastic has been reported (Singh, et al. 2003). Sample were prepared from an SBS (20%wt. to 30%\wt.) modified bitumen, with varying contents of coarse and micronized H_2O_2-treated PVC particulates (60%-70%wt.), along with limestone dust (7%-15%wt.). The ozonized PVC waste demonstrates a better performance in terms of improved viscoelastic properties (as indicated by DMA-Dynamic Mechanical Analysis, rheometer test result etc.). This is attributed to a lower molecular mass, a much rougher and porous surface nature of the treated particles as shown by evidence from a UV-visible spectrometer and SEM (Scanning Electron Microscope), which leads to a consistent and better particle-bitumen anchorage. A roof mastic composition of treated coarse and micronized PVC waste, Isocyanate waste, limestone dust, anti-oxidant, rosin and SBS

Garcia-Morales, et al. studied rheological characteristics and microstructure of recycled EVA-modified bitumen by conducting OSTs (oscillatory shear tests) in the linear viscoelasticity region, modulated differential scanning calorimetry, & optical microscopy (Garci'a-Morales, et al. 2003). They found a significant increase in storage and loss moduli values at high temperature indicating increased resistance to permanent deformation. Micro-structural change was also observed when polymer content is attained up to 9% in the blends, this is associated to correlation between large swollen polymer particles. Modified bitumen that satisfied the Indian specification (IS 1195-90 Bitumen Mastic for Flooring) was finalized.

Furthermore, the modification of asphalt binder for roofing by PVC packaging waste has been conducted (Fang, et al. 2009). Samples from asphalt containing (0-10%wt. of asphalt) PVC waste were subjected to low temperature flexibility test, elongation and tension test, alkali and acid resistance test, softening point, ductility and penetration test during a 12 months aging cycle period. The results reveal positive performance improvements. This is connected to the FT-IR findings that shows negligible difference in the locations and magnitude of peaks in absorption band between the modified and the neat asphalt, which insinuates a compatible physical interaction among the PVC waste and the light oil asphalt constituents. Additional microscopic image shows the emergence of disperse and continuous polymer-rich microstructure with increasing polymer content.

The effect of toner cartridge recycled plastic waste on the properties and behavior of asphalt binder was examined (Yildirim, et al. 2004). The research was funded by Texas Department of Transport, in an attempt to improve hot mix asphalt performance and facilitate the means of recycling toner cartridge waste. Three test road sections having different type of toner composition were constructed at different location. The toner level required to achieve different super pave performance grading were established for each type of toner waste. Bending beam rheometer results shows increase stiffness (m-value) for the modified asphalt, indicating higher tendency of susceptibility to lower temperature cracking. 60 to 90 minutes was found to be the required mixing time to obtain a homogenous mix. But the asphalt-toner blends exhibit lower thermal storage stability.

Rahman et al. (2006) conducted an economical assessment of using and preparing of MPW (mixed plastic waste) with VR (vacuum residue) or without vacuum residue in Saudi Arabian condition. They studied and collected all the associated costs related to preparing of MPW and conduct sensitivity and profitability analysis. They found that processing of mixed plastic waste with vacuum residue at containing of 200,000 tons per annum (TPA) (80,000 TPA MPW & 120,000 TPA VR) to be financially viable for Saudi Arabian conditions with 14.6% of IRR (internal rate of return)values along with 6.4 years of payback time and 47.6%of break-even capacity.

Compatibility between bitumen and polymer is another important issue in selecting appropriate bitumen that is basically determined by laboratory experiment but still there are some theoretical trends that can be followed. Lesueur (2009) conducted his research to mitigate the present state of bitumen science, with particular importance on the correlation between the formation & the rheological characteristics. It intended to show a straightforward physical picture of bitumen that assists comprehend familiar outcomes on the impact of various modifiers. His article reviewed the recent apprehending of bitumen formation& the results in terms of characteristics, with a powerful importance on the rheological features.

Ameri et al (2011) utilized gilsonite (resinous hydrocarbon widely available in Iran) with the asphalt of PG58-22 and PG64-22 to improve its grade. They blending process were done in two different temperature and rotational speed, First 150 minutes were done at

140^0C with speed 150rpm and the next 30 minutes were at 180^0C with 4500rpm speed. Addition of 12% Gilsonite showed a change of higher temperature ranges from 64^0C to 82^0C however it reduces lower temperature ranges.

Syroezhkoet et al. (2002) examined using elastoplastic for the improvement of asphalt properties from north-western Russia. DST-30 divinyl styrene elastoplastic rubber was added while the temperature of fresh asphalt was 180-200^{o}C blend was stirred for 1.5 h at 1250 rpm. Their modification has improved the working temperature range from - (25-27) to + (44-50)^{o}C (for unmodified) to -3(32-35) to + (90-95)^{o}C (for modified).

Kim et al. (2014) conducted an experiment to evaluate the distortion resistance at higher temperature, resistance to fatigue & tensile hardiness at existing temperature related to crumb rubber modifier (CRM) bitumen mix. They also studied the moisture sensitivity after freezing-and-thawing (F/T) analysis by ITS (indirect tensile strength) test. They found that fatigue resistances of crumb rubber modified (CRM) mixtures were noticeably increased than the conventional mixture, however the moisture resistance after freezing-and-thawing treatment was observed too low. Because of the lower performance of the CRM mixtures regard to moisture susceptibility . Finally, they demonstrated that CRM-mixing comprising the hydrated lime had marked enhancement in moisture susceptibility.

Xue et al. (2014) used rice husk ash (RHA) and wood sawdust ash (WSA) to modify asphalt binder. They used FT-IR Spectroscopy for specifying impacts of biomass ashes on chemical properties of bitumen binder. From the experiment, they showed that there is no chemical reply between asphalt binder and biomass ash (BA). By conducting storage stability tests they exhibited that the asphalt binder modified with RHA and WSA is fixed whenever ash content is below 20%. They examined DSR test to indicate that modified asphalt binders showed more complex modulus & lower stage angle under testing temperatures. Finally, they were able to show that RHA and WSA can be considered as asphalt modifiers which were more helpful for the improvement of rutting resistance.

Qin et al. (2014) investigated field aging effect on asphalt rheology and structure to establish thestructure-rheological property relationships with the ultimate goal of predicting rheology of field aged binders. They explored chemistry–property relationships of asphalts under various aging conditions. Although binder aging is evident in rheology, the temperature dependence of rheology does not change with aging for the unmodified binder investigated in this work. In addition, the effect of aging on low temperature rheology they investigated by 4 mm diameter parallel plates DSR with machine compliance correction. They proposed a method to predict binder rheology under varying aging severities or at different pavement depths. The prediction is based on the binder chemical-rheological property relationships and CA model, and shows good agreement with experimental results. Further study is needed to validate this method on a wide array of binders and modification processes.

A number of experiments has outlined on the salient features & characteristics of asphalt rubber mixtures by means of developed everlasting malformation and fatigue cracking. Kaloush (2014) summarized outcomes from various research studies organized at Arizona State University in the areas of binder & mixture performance and recommended to apply them in recent pavement design strategies.

Bueno et al. (2014) proposed a new experimental method to specify the low temperature behaviour of bituminous binders with the dynamic shear rheometer (DSR). They analyzed operational parameters (such as shear strain amplitude or loading frequency) to develop a reproducible procedure applicable for different bituminous binders. The CSC-failure test method is capable to differentiate different types of bituminous binders and ageing states. Moreover, the mechanism of the failure was qualitatively described. They concluded that the fracture is disseminating radially inside the sample from the outer edge. They suggested further investigation to analyze the effect of a different starting temperature considering the viscosities of the binder at intermediate temperatures when testing hard bitumen due to its high failure temperature close to the start temperature (20 ^{o}C).

Underwood and Kim (2014) derived a newly physico-chemical correlation based micro-mechanical replica and assessed to forecast bitumen mastic stiffness as a function of particle engrossment. The major purpose of their study were to exhibit the limitations of existing weak suspension and micro-mechanical models and to suggest a micro-mechanical structure that regards for physico-chemical relationships inside the asphalt mastic that can more correctly estimate the impact of particle engrossment on the mixed modulus of asphalt mastic. But the main drawback of the proposed method is the need for this replica has been recognized after estimating 12 distinct existing formulas across a range of 64 various temperature & frequency amalgamations. Further investigation should be conducted to show the validity of the proposed method.

Hamzah et al. (2014) proposed a new method based on image analysis to evaluate the adhesion failure due to moisture on fractured conditioned asphalt surfaces. Their outcomes from the image analysis demonstrated that adhesion failure increased with the number of F-T (Freeze Thaw) cycles and mixtures prepared using PG-76 binder displayed lower adhesion failure compared to PG-64 binder. Their proposed method entitled estimation of adhesive failure of mixtures prepared using different binders and levels of laboratory moisture conditioning. Finally, they demonstrated that the image analysis method can be used to quantify adhesive failure of warm mix asphalt and is a better alternative to the conventional method of visualization using the naked eye.

Luong et al. (2014) conducted their study to establish a non-destructive technique applied to ultrathin porous asphalt pavements that allows to characterize their internal structure. They measured absorption coefficients using an impedance tube described in the experimental techniques part. They applied their method to high porous specimens compacted in ultrathin layers. Ultimately, they revealed that using a high viscosity asphalt rubber binder has no influence on maximum acoustic absorption but on the frequency of appearance of this maximum, tortuosity and airflow resistivity.

Qin et al. (2014) investigated microstructure feature relationships of Sasobit modified WMA (Warm Mix Asphalts) by means of thermal, rheological & morphological analysis. They encompassed in their study 4 bitumen samples with several grades & dosages sasobit concentrations (1% & 3% by weight). Network and dendrite formations are demonstrated Sasobit blends of 3% and 1% in their work. They showed that gel formation is accountable for the break-down of time-temperature superposition. They also investigated that the network/dendritic microstructure comes to light only contingent on the Sasobit concentration, nonetheless of asphalt kinds& grades. Eventually, they stated that Sasobit is not assumed to display an extreme negative impact on performance at lower temperature as recommended by $2^{o}C$ increment of the bounding low temperatures.

Delbon and Giudice (2014) conducted an investigation to study the adherence of multilayer pavements, on laboratory scale, formed by a standard concrete, two modified asphalt emulsions with different melting points, a grid based on polyester fibers attached to a non-woven polypropylene geotextile and finally, conventional asphalt applied at different temperatures. The results of their study explained the causes of habitual faults that occur in rehabilitated pavements. They demonstrated that the interface of system based on concrete/geo-synthetic applied on the modified asphalt emulsion as bonding agent/asphalt mix was more convenient than that achieved by the concrete/asphalt emulsion/asphalt mix. Their tests also indicate that the introduction of geosynthetic between the concrete and the asphalt layer improved the adherence provided that the base material of geo-synthetic is melted. They stated that deformations at maximum load were higher when a grid was used between layers and energy absorbed increased when polymeric grid allowed the contact between layers.

Yut and Zofka (2014) investigate the relationship between rheological properties of aged polymer-modified asphalts (PMA) with their chemical composition in laboratory. However, their main purpose was to instigate the impact of polymer modification on viscoelastic characteristics of modified asphalts and to manifest interrelationship between chemical & rheological changes in polymer-modified. Their statistical inspection of dynamic shear rheology (DSR) and ATR FT-IR estimates covered cross-tabulation analysis, multiple linear regression & analysis of variance. From the analysis of variance estimates they demonstrated that graveness of aging procedure influenced polymer modified asphalt viscosity greater than polymer configuration & concentration did. They used laboratory aging procedures in their study; therefore further research is required with the samples obtained from the field.

Xiao et al. (2014) studied rheology on SBS (styrene butadiene styrene used for producing PG 76-22 binder) and three unorthodox binders with/without PPA (polyphosphoric acid). The results of their experiment exhibited that the impacts of unorthodox polymers & PPA on the $G^*/\sin\delta$ values was due to control binder. The main purpose of their research was to instigate the upper temperature characteristics of SBS & three unorthodox polymer modified binders with/without PPA. They were able to show that the performance Grade, PG 76-22 binders with two radical polymers had significantly lower viscosity values comparing with SBS modified binders & thus necessitated lesser energy for mixing and compaction. They also demonstrated that the utilization of 0.5 percentage of PPA could lessen by 1.0% of additional polymer required to make the PG 76-22 binder. Furthermore, key finding of their research were binders rheology depends on type of polymer, source of asphalt and test temperature.

Rheological properties of asphalts blended with soybean acidulated soapstock, a relatively low-cost and highly concentrated source of soybean fatty acids was inspected by Seidel and Haddock (2014). They conducted typical tests of bitumen and performance-graded asphalt binder tests. They subjected the base asphalt binders to three traditional binder tests, mass change (AASHTO T 240-06), softening point (AASHTO T 53-09) and rotational viscosity (AASHTO T 316-04). Their findings suggested that SAS (soybean acidulated soapstock) could be used as a fluxing agent for stiff, hard and viscous asphalt binders, increasing their workability and may improve lower temperature performance of an asphalt binder by reducing thermal stress development. Seidel and Haddock (2014) included only high and low temperature asphalt binder properties not intermediate temperature properties, such as resistance to fatigue cracking and moisture sensitivity, were not investigated.

Muniandy et al. (2014) estimated the modified and without modified binders fatigue strength in Stone Mastic Asphalt (SMA) mixtures utilizing advanced crack meander (CM) method. Some isolated features of their technique comprised instigation of all features of fatigue distress clarity of the test and the higher accuracy of the image processing method. They took specimens images within the replicated load ITFT (indirect tensile fatigue test) & analysed crack induction, procreation and failure applying an advanced ‘‘Measurement & Mapping of Crack Meander’’ (MMCM) Software. Their final assessment was performance of fatigue can be resolved employing crack occurrence as an alternating technique of strain or dynamic modulus plots. Since their research was finite to three distinct mixtures only, it is suggested to add more mixture types in the further research to strength the assurance of applying this method.

Li et al. (2014) introduced an (advanced repeated load permanent deformation) ARLPD test to estimate rutting defiance of asphalt pavements at field circumstances. They conducted it over the multi-phase specimen for 18 distinct shape integration of asphalt layer in newly manufactured pavement & rehabilitation projects at several temperatures. They investigated the combined rutting resistance & distribution using different rutting measures. Eventually, they validated their test results by the long term pavement performance data.

Modarres and Hamedi (2014) conducted a research to instigate the impact of waste plastic bottles on the inflexibility & specifically fatigue features of asphalt mixtures at two distinct temperatures of 5^0& 20^0 C. They assess the fatigue performance of Polyethylene Terephthalate (PET) modified mixtures comparing with unmodified asphalt mixtures. Also, they made a comparison of the inflexibility and fatigue features of Polyethylene Terephthalate modified mixtures with that of modified by styrene butadiene styrene. Although at 5^{o}C the SBS fatigue life modified mixtures was to some explore higher than that of Polyethylene Terephthalate modified ones specifically at more strain levels of 200 micro strain, they demonstrated that at both temperatures, polyethylene terephthalate extended the fatigue performance of studied mixtures.

Sulyman et al. (2014) presented their work to aid intent readers to be acquainted with the paving material asphalt-modifiers attained from SIW by supplying factual view point on its first innovation and evolution. They also highlighted on ordinary approaches of asphalt mixing production along with two asphalt producing mechanisms :(a) warm mix asphalt (WMA) & (b) hot mix asphalt (HMA), and the different merits of each mechanism. Moreover, their research paper supplied the candidate with an outline of some surveys organized by scientists & researchers that are influential in formation of roads with very proficient pavements and enhanced longevity and pavement behaviour.

Min and Jeong (2013) examined the thermal characteristics by differential scanning calorimetry (DSC) which showed that flexible aliphatic hydrocarbons (FAH) in maltenestage or paraffin wax, preferably vanished into the trans-polyoctenamer rubber (TOR)stage from the Air-blown asphalt (ABA)stage. With a rheometer they also examined rheological properties by frequency sweep & temperature sweep which recommended that the polymer modified asphalt (PMA) is a multistage system comprised of a stage made by maltenes, a mesoscopic stage affluent in asphaltenes, & a TOR stage swelled by vanished maltenes. Eventually, they proved that TOR can be utilized effectively for asphalt modification and the modulus, elasticity, & the temperature susceptibility of air-blown asphalt were enhanced by modification with trans-polyoctenamer rubber(TOR).

Darabi et al. (2013) presented a viscodamage model that can logically forecast the fatigue damage response of asphalt concrete materials with respect to several loading circumstances. Their proposed theory of the continuum damage-healing (CDH) mechanics noticeably clarifies the coupling between the visco-elastic–viscoplastic structures with the viscodamage & micro-damage healing structures. They validated their proposed model against substantial research data covering constant strain rate (CSR), cyclic displacement controlled (CDC), and cyclic stress controlled (CSC) tests over a field of temperatures, strain rates, loading frequencies, & stress/ strain levels/amplitudes. They also illustrated the VE–VP–VD–H replica capable of forecasting the fatigue damage response of asphalt concrete with respect to various loading states.

Toraldo et al. (2013) conducted a comparative laboratory study focusing on the impacts of synthetic wax as a preservative for warm mix asphalts. They conducted their experiment in the Road Research Laboratory (RRL) at the Politecnico di Milano which was splited into two principal phases to estimate the working temperatures on: (a) compaction & volumetric parameters and (b) the mechanical performance of two distinct asphalt mixtures for wearing courses. Experiment exhibited that wax improves constructability parameters at low temperature of compaction and thermal dependence of asphalt concrete reduces with wax. They also showed that fatigue resistance of warm mix asphalts (WMA) is unconventional from the compaction temperature and better gullible to destruct from repeated loads than hot mix asphalts (HMA).

EI-Wahab et al. (2013) conducted a research highlighting on the latent collaboration of mixing asphalt cement, having penetration grade 60/70, with polyesteramide (PEA) resin to manufacture industrial covering for steel utilizations, with the goal of solving the steady drying time of the asphalt cement and the respective fragility of PEA resin. In order to reach this goal, they mixed polyester amide (PEA) resin with 3 to 12% (w/w) asphalt cement range. The results of the experiment terminated that normally, a blend of asphalt cement &PEA resin manufactures an effectual material for industrial coating utilizations. Their research also displayed that 9% & 12% polyester amide resin content formed good-quality anti-caustic material comparing with virgin asphalt cement.

Wei et al. (2013) regulated an experiment to characterize the APAO (amorphous poly alpha olefin) rheological features of modified asphalt binders. They investigated the rheological properties of APAO modified asphalt binders with internal viscometer (RV), dynamic shear rheometer (DSR), & bending beam rheometer (BBR) tests in the laboratory. Results of their study indicated that APAO improves the high temperature performance of asphalt binders and addition of APAO reduces the temperature susceptibility of asphalt binders. Their study also detected that APAO K3050 has better modification than K3020 due to its higher viscosity. They only investigated the rheological performance of APAO modified asphalt binders. Therefore, additional laboratory mixture research supplemented with field validation is strongly recommended to validate the findings of this research.

Yan et al. (2013) examined the impacts of PPA (polyphosphoric acid) on chemical structure, physical properties & morphology of several bitumens. They also evaluated the interrelationship between morphology and chemical structure along with physical properties. Findings of the research exhibited that the influence of PPA (polyphosphoric acid) on different bitumen determined by the base bitumen and the PPA modification is influenced by the colloidal index of base bitumen. They also found a severe interrelation between morphology and chemical structure along with physical characteristics for several bitumen after PPA modification.

Parvez et al. (2013) conducted an investigation utilizing waste crumb rubber (WCR) & sulphur to improve the performance of asphalt binder for pavement utilizations. The aim of their research was to boost the applications of two by-products sulphur& crumb rubber in asphalt modification. They applied 20-50% sulphur range to make sulphur asphalt binder whenever they used 1-6% rubber range. They investigated melt properties employing thermal analysis, dynamic & steady shear rheology (SSR), and artificial aging. Results of their investigation showed that the crumb rubber-modified (CRM) sulphur asphalt exhibited better properties comparing with traditional asphalt binder and application of these two by-products in asphalt modification can cover the additional demand for asphalt, lessen the price, and amplify asphalt pavement life and also assist in resolving the waste disposal problem and sustain environment fair.

Kim et al. (2013) suggested a method that state highway agencies (SHAs) of the USA used to estimate pavement using both economic & non-economic event. Their study revealed the scope to which the 4 pavement schemes affect the quality & costs related to highway construction and maintenance throughout the life of every pavement scheme.

Their studies provoked in rank-ordering the pavements depending on the long-run performance. These outcomes of the experiments and rank-orderings will be applied to recognize and layout further research that Caterpillar might commit to enhance whole life cycle costs inside the road renewal industry.

Ameri et al. (2013) presented a lab assessment of the respective performance of a sequence of ethylene vinyleacitate (EVA)-modified bituminous materials with regard to the 3 modes of pavement distress rutting, fatigue cracking & low temperature cracking. They used two methods in this study to estimate the comparative performance of a sequence of polymer modified bituminous materials. First approach was comprised of bitumen-based pavement performance projection parameters whether second one was comprised of pragmatic mechanical characteristic of asphalt concrete mixing testing with laboratory assessments of asphalt concrete mixing perpetual deformation, fatigue & low temperature cracking behaviour. Their research showed that EVA-modified bitumen rutting resistance is greater than that of base bitumen &EVA-modified HMA rutting resistance is higher than that of traditional HMA. The experiment also established that EVA-modified HMA fatigue life is more than that of natural HMA and inclusion of EVA of up to four percent boost low temperature performance of base bitumen.

Vargas et al (2013) organized a research to assess the thermal stability, morphology, & viscoelastic properties of asphalts modified by several types of polyethylene and their grafted polyethylene additives for potential employ in asphalt pavement. They employed fluorescence microscopy to gain information on morphological blends and applied rheological tests to evaluate the viscoelastic characteristics of asphalt blends. Fluorescence microscopy (FM) showed that non-grafted polyethylene polymers (NGPE) were not readily miscible with asphalt & rheological tests indicated that most of the asphalt blends display improvement at higher temperature with grafted polyethylene (GPE).

Thives et al. (2013) presented an appraisal of the absorption time of asphalt rubber binders manipulating conventional performance-related (CPR) tests & scanning electron microscopy SEM) tests to assess the outside of the asphalt rubber binder. They used two distinct crumb rubber modifiers (CRM): (a) the first crumb rubber was obtained by grinding tires at ambient temperature and (b) the second one was obtained by grinding at cryogenic temperature. The main purpose of their study was to bestow to the evaluation of the absorption time of asphalt rubber binder depending on microscopy analysis. They stated that the SEM is necessary tool for assigning the dissolution time of asphalt rubber.

Marajo et al. (2013) conducted a study to make a comparison of the impact of weathering on the aging of traditional and modified asphalt binders by styrene-butadiene-styrene (SBS), hydrated lime (HL), reactive ethylene ter polymer, & polyphosphoric acid employing Fourier transform infrared spectroscopy (FTIS) and thermal analysis. They analyzed the humiliation of the samples utilizing FTIS& thermal analysis. They observed that the improvement of thermal stability with aging for traditional asphalt binders, PPA asphalt binders, & SBS asphalt binders. They also found that the maximum decomposition temperature rate increased along with the temperature of terminal decomposition after aging for the styrene-butadiene-styrene (SBS) asphalt binders & for the hydrated lime (HL) asphalt binders.

Presti (2013) introduced the Recycled Tyre Rubber (RTR) material as environmental problem as well as engineering resource and described some literature review upon the existing technologies and specifications related to the production, handling and storage of RTR-MBs and on their current applications within road asphalt mixtures. He also introduced the wet process technology and described in details the existing products associated to the wet process high viscosity technology. He compared the described technologies and providing justifications and suggestions toward a widespread use of RTR-MBs.

Atherton et al. (2012) performed their research to collate the mechanical features of conventional HMA & modified cold bituminous liniment mixtures integrated with lavish materials. Outcome their experiment highlighted on realizing the consequence of the LJMU-FAI on upgrading the engineering phenomenon of close graded surface course CBEM's (Cold Bitumen Emulsion Mixtures) by means of stiffness modulus & creep stiffness. They used the waste materials as a modifier of the Cold Bitumen Emulsion Mixtures. The results of their experiment exhibited that a remarkable enhancement by means of the mechanical characteristics of the new cold mixtures owing to the use of the by-product materials in disparity with the features of conventional hot mixtures.

Alatas et al. (2012) comparatively investigated the capabilities of HMAs made with the similar performance bitumen with Superpave design technique by testing process. Moreover, they evaluated the impact of asphalt modification utilizing SBS to the mechanical properties of asphalt mix. They found that the mixtures made by the similar performance asphalt following to Superpave design method demonstrated different performances.

Xiang et al. (2009) proposed matrix asphalt preblending process (MAPP) to manufacture Crumb rubber modified asphalt (CRMA). In the new process they used matrix asphalt as swelling agent in lieu of oil slurry. Through MAPP with crumb rubber they modified asphalt Zhonghai AH-70. Depend on the capability of CRMA, they investigated the consequence of the portion of pre-blending matrix asphalt (PMA) and characteristics of crumb rubber. Moreover, they observed the Armand micro-structures of crumb rubber powder through SEM(scanning electronic microscope) & fluorescence microscope, respectively. Outcome of their experimental showed that the CRMA have better performance over the matrix asphalt; the crumb rubber properties revealed important effects on the performance of CRMA, with the decrease of ash content and the increase of acetone extract performance of CRMA are improved.

Giuliani et al. (2009) used a normal procedure to estimate the asphalts fuel resistance. They analysed with this procedure some PMA (assemled from two bases and 4 or 6 wt% of different polymers) and the interrelationships between resistance of fuel & morphology of the polymer modified asphalts, the chemical formation of the polymers & the configuration of the asphalt were evaluated. They showed that the affinity of asphalt/polymer which can be directly interrelated to the fuel resistance; and the structural analysis of the asphalt permit to forecast a polymer that can improve fuel resistance.

Sengoz and Isikykar (2008) presented a laboratory study to specify the characteristics of the SBS & EVA modified binders by using usual & empirical test procedures along with to assess the morphology by analysing condition of dispersion of SBS & EVA polymer & bitumen phases. The mechanical properties of the hot-mix asphalt (containing SBS and

EVA PMB & collated with HMA integrating base bitumen) was also analysed by them. Outcomes of their study revealed that, the morphology & characteristics of the modified asphalt, along with mechanical features of polymer modified asphalt mix are dependent on the nature of polymer and their different content. Moreover, they summarized that, the mechanical features of HMA assembled with the SBS PMB samples for instance Marshall Stability was extended with polymer contents increment.

Widyatmoko & Elliott (2008) presented in their paper the outcomes from a sequence of evaluations of ‘empirical’ and rheological characteristics of bituminous binders, that integrate raw asphalts (TLA &Initiate) and/or polymer modifiers. They showed that ‘empirical’ characteristics of binder, estimated by penetration and Ring. Ball softening point tests, indicated that raw asphalts decrease or increase these corresponding ‘‘empirical’’ estimates at the level predicted by ‘‘conventional blending formulas’’. Though, analysis of rheology demonstrated that the ‘‘stiffening’’ effect originated by inclusion of raw asphalts, took place in a different way if a polymer modifier was also included, which is naturally expected in the case of asphalt integrating unmodified bitumen.

El Ashry et al. (2008) investigated the change in physicochemical properties due to fluxing propane precipitated asphalt (PPA) as well as blown asphalt grade 115/15 of marine belayim Oregon with long residue (LR), short residue (SR), and aromatic extract (AE). They prepared asphalt samples by fluxing PPA with AE, Their experimental result showed that for softening point, fluxed PPA samples showed decreasing trend in softening point as the AE.

Polacco et al. (2006) presented a short explanation of linear rheological characteristics and modelling. They also paid specific notice to the recently studied research on the functions of material, like shear viscosity & relaxation modulus in a nonlinear visco-elastic area. Furthermore, they described the interrelationship of nonlinear action with polymer properties and with the planning settled whenever polymers are blended with bitumen.

Polacco et al. (2005) used in their research different polyethylene (PE) related copolymers for the modification of asphalt of 70/100 penetration grade. They analyzed the morphology and storage stability which revealed materials were mostly bi-phasic and there were tendency to separate into two phases such as (a) polymer rich & (b) asphalt rich. Their study also includes rheology of virgin asphalt & modified asphalts with various dosages (%) of this modifier. The rheological analysis suggested a There is possibility of creation of small crosslinking, and the reason might be thermo-mechanical stress at the time of mixing.

Leonenko and Safonov (2001) conducted a research to examine modification of petroleum asphalts with polymeric materials. They used polymers containing a crystalline phase as modifiers. To determine the lower concentration of cross-linking of the polymer in the polymer–asphalt composite they obtained a relation based on an adsorption model of the reaction of the polymer with the disperse phase of the asphalt. They established that the total maximum content of asphalt in the polymer and disperse phase should not exceed 25%.

2.2 Summary of Review

Table 2-1 describes the Strategic Development (in chronological order) of the technology related to PMB which include some important milestone in this field along with some achievement and challenges faced by different researchers.

Table 2-1: Strategic Development of PMB-Review Summery

Natural Bitumen (Ancient Age)	People used bitumen as waterproofing, preservative and as binder material in Pavement (Polacco et al. 2006)
Refined Bitumen (Early 1900)	First production of refined asphalt from refining crude oil in the USA (Polacco et al. 2006)
First Modification of Bitumen (1950)	An well-known plastomer named neoprene was used as first modifier of bitumen in USA (Yildirim 2007)
Commercial Production of Polymer(Early 1960)	Most common plastomers were started to produced commercially (Utracki 1995) on the other hand elastomer (SBS) were produced in the USA in 1965 (Utracki 1995)
First Modification by PP (1965)	For the first time polypropylene was used as modifier of bitumen in Italy for the roofing purposes and then commercially promoted in 1967 (Johnson 1987)
First Modification by SBS (1970 in Europe & 1978 in USA)	USA started commercial manufacture of PMB around 1980 (Johnson 1987)
First PMB for Paving industry (1972, 1976, 1978)	In 1972 – FHWA of USA started investigation of utilizing polymer actually elastomers for the improvement of the bitumen for paving industries. They found improvement of

	rupture resistance of PMB (Rostler et al. 1972). In around 1976. German and French separately investigated the utilization of polymer and found PMB to be good resistant to permanent deformation and decreasing temperature sensitivity (Zenke 1976) (Kameua and Duron 1976). In 1978 FHWA of USA investigated utilization of SBS latex, Neoprene latex and PP with different grade (penetration grade) of asphalt their laboratory data indicated the increment of impact resistance and reducing the brittleness at low temperature and reduced loses of properties after exposure in the thin film oven test. For the first time they also reported the storage stability problem of their modified bitumen (Chaffin et al. 1978).
More Systematic Research on PMB (in 1980, 1982)	Detail investigation has revealed some improvement of asphalt however some researchers have found that polymer modified bitumen exhibits the following problems/ challenges : **a)** storage stability problem **(**Chaffin et al. 1978**)** b) swelling of polymers in bitumen (Kraus 1982) c) phase separation problem (Denning and Carswell 1983) d) higher temperatures for (production and compaction)

	(Denning and Carswell 1983) e) High cost of PMB (Bowering 1984)
Performance Based Specification (1987)	Strategic Highway Research Program (SHRP) developed new powerful tools which is Performance Based Specification of asphalt binder evaluation and new grading (PG) system that give a new dimension of the research for the modification of asphalt.
Field test of PMB (1989)	In California Reese R et. al. conducted a two year filed test of PMB and found good resistance to cracking and aging (Reese and Predoehl 1989)
More Advanced Research (in 1990s)	Researchers from different (Australia, Austria. Belgium, Germany, Gulf Countries, Japan, Poland, Spain and Nordic Countries) country (Isacsson and Lu 1995) started systematic investigation about PMB giving particular focus on temperature susceptibility, morphology, thermal behaviour and mechanical properties. Most of the cases they have found some improvement (cracking Resistance, elastic recovery and rutting resistance) with some challenges like storage stability problem, swelling of polymers, phase separation and higher cost of commercial polymer.
Advanced Research in Gulf Region (1997, 1998, 2002)	AI-Abdul Wahhab et. al. (1997) conducted an extensive research for the first time in Gulf region to develop performance-based bitumen specification. One of the

	important outcomes of that research is suitable temperature zoning of gulf countries (Figure: 2.1) based on SHRP specification. Their findings also revealed that: a. Penetration grade and Viscosity are not suitable bases for bitumen specification b. Temperature zones ranges from PG58-10 to PG 76-10 c. Bitumen produced locally need modification to adapt gulf temperature zone Followed by this research several researcher Al-Abdul Wahhab et. al. (2002), Al-Dubabeet al., 1998 conducted research for modification of asphalt to attain PG requirement. Different commercial elastomer (SBS, Crumb rubber) and plastomers (LDPE, HDPE, polystyrene, polybilt) For Riyadh asphalt 3% LDPE (grade 1182) or 10% Crumb rubber tires or 1.5% polypropylene (grade 500U) were found most favourable.
Modification by Recycled Polymer (Green Modification) (2003-2015)	Researchers from different places started utilizing waste plastic with more concern environmental protection and economy (Zhu,2014). Based on the findings of all encountered literature it has found that recycled polymer by Singh, et al. 2003, they used waste PVC and found some positive performance improvements. They also concluded

	that increasing polymer content can result disperse and continuous polymer-rich microstructure.

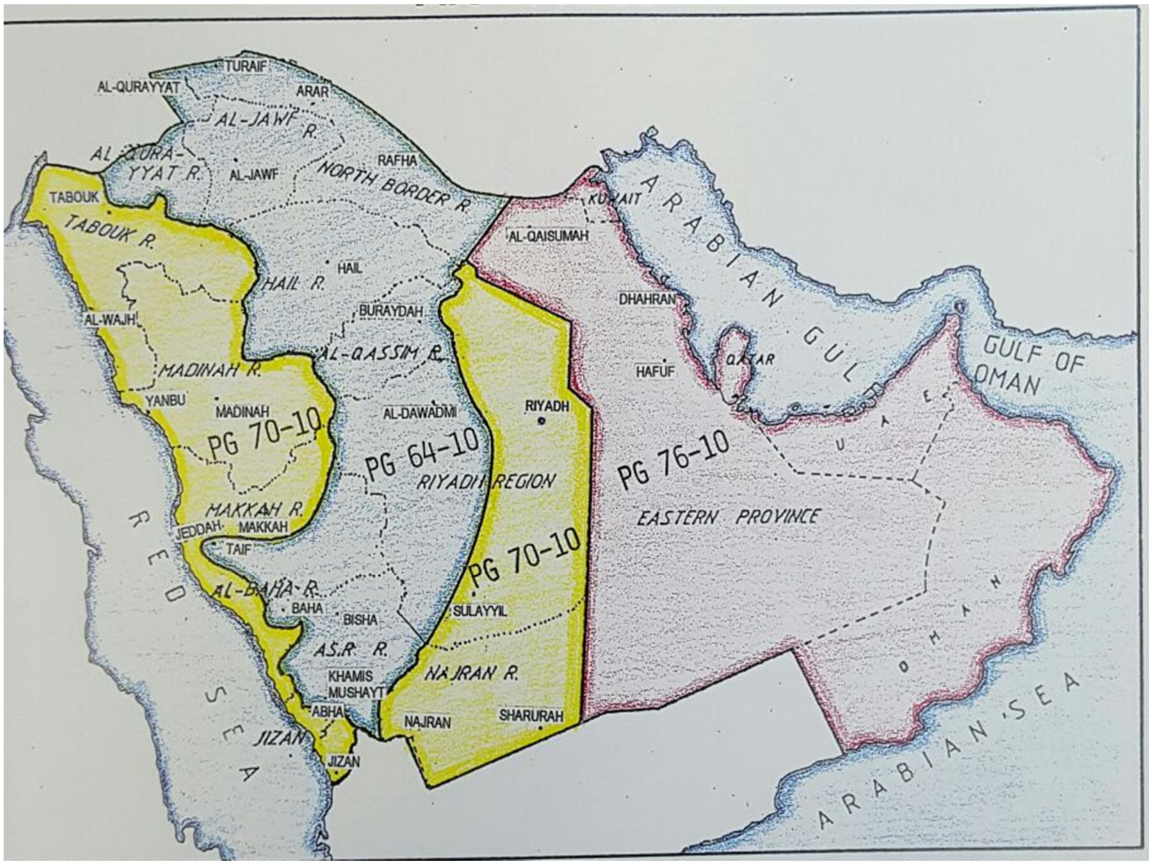


Figure 2.1: Temperature Zoning for Gulf Countries (AI-Abdul Wahhab et. al.,1997)

Based on the above discussion it has been observed that the following challenges/ problems still need to address in the field of PMB.

a) High cost of commercial Modifier
b) High Melting temperature and long blending time (polymer agglomeration, oxidation)
c) Improving the less elasticity of plastomeric polymer modified asphalt
d) Storage Stability Problem
e) Swelling of polymers in bitumen

f) Phase separation problem

g) Higher temperatures for (production and compaction)

h) Higher dosages of SBS causes a problem in asphalt mix (repulsive force between particles become higher than attractive force) (Li et al. 2012)

Current study focuses to resolve the first two problems. Optimization techniques were taken to determine the minimum blending time for each blend, furthermore this is the first time study of utilization of recycled polymer in gulf asphalt. On the other hand this study will also focus on the reduction of utilization of commercial SBS that will be beneficial in terms of economy in one side and other side it will also eliminate problems associated with utilization of high content SBS.

CHAPTER 3

METHODOLOGY

3.1 Material Collection and Processing

In this research, three different recycled plastic materials (rHDPE, rLDPE, rPP) and two commercial polymers (cSBS, cPB) were used with control binders. This chapter describes the material acquisition and their processing with the following sub sections.

3.1.1 Virgin Asphalt Binder

The raw asphalt used in this study was collected from Ras-Tanura refinery located at Eastern Province in Saudi Arabia. The asphalt binder also was characterized through basic viscosity, Cleveland open cup flash and fire point test (ASTM D92). Finally, the asphalt was checked according to Practice for Grading or Verifying the Performance Grade of an Asphalt Binder (AASHTO PP6).

3.1.2 Recycled & Commercial Polymer Acquisition and Processing

The mentioned local recycled wastes (LDPE, HDPE and PP) were identified and handpicked from the KFUPM Central Cafeteria Waste Bin. Widely used recycling symbol were used to identify the type of material. These wastes were then processed for easier use. The processing steps are illustrated in Figure 3.11.

Table 3-1: Basic physical properties of polymers

Polymer	Code	Source/Nature	Melting Point (°C)	Density(g/cm^3)
HDPE	H	Recycled Waste	150	0.950
LDPE	L	Recycled Waste	130	0.940
PP	P	Recycled Waste	160	0.946
SBS	S	Commercial	180	1.060
Polybilt	B	Commercial	140	0.943

Virgin polymers which include one plastomer (i.e. Polybilt 101) and one elastomer (i.e. SBS calprene) type were acquired from a commercial source. (Figures 3.1 and 3.2 show some commercial polymer and recycled polymer respectively) Table 3-1 shows some basic properties of recycled and commercial polymer which were used in this research. The RPW processing involves: Cleaning, cutting, shredding and grinding.

Figure 3.1: Commercial Polymer Used in this Study

Figure 3.2: Recycled Polymer Used in this study

a. **Cleaning**: Label were removed from some RPW and then cleaned by washing and drying to ensure the purity.

b. **Cutting, Shredding and Grinding**: The recycled LDPE, HDPE and PP were first cut to make them suitably fed in the Polymer Extrusion Machine (Figure 3.3 shows Polymer sample before feeding them in extruder machine). Then using that machine shredding and some even grounding were done to ensure homogeneous mixing and melting with the asphalt. Figure 3.4 and 3.5 shows Polymer Extrusion Machine and the polymer dust after extrusion respectively.

Figure 3.3: Polymer sample before feeding them in extruder machine

Figure 3.4: Polymer Extrusion Machine

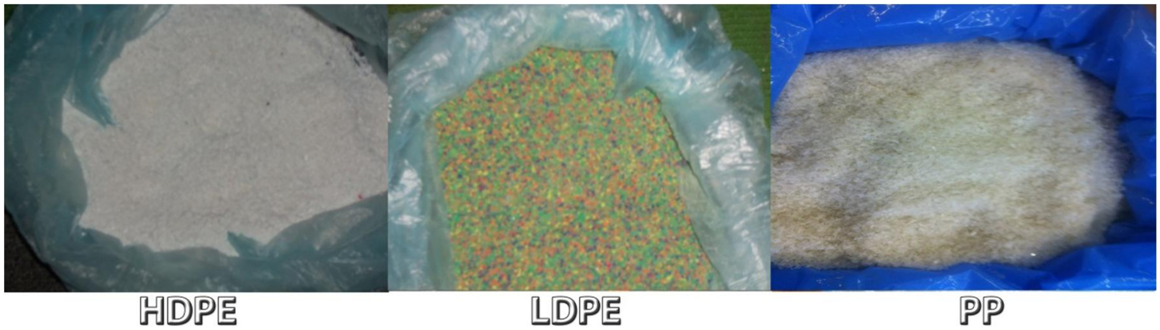


Figure 3.5: Polymer dust after extrusion

c. Differential Scanning Calorimetry (DSC) test of RPW Sample: DSC was conducted for the recycled LDPE, HDPE and PP to know the melting point and the melting nature of the sample. This result guides us to determine / optimize the blending temperature to mix with virgin asphalt.

3.2 Sample Notation and Experimental Design Setting

Table 3-2 shows some important elaboration and notation used in this research.

Table 3-2: Notation for different Samples

Sample Notation	Expression/ Meaning
rHDPE	Recycled High Density Polyethylene
rLDPE	Recycled Low Density Polyethylene
rPP	Recycled Polypropylene
cSBS	Commercial Styrene Butadiene Styrene
cPB	Commercial Polybilt
H2S1	2% Recycled High Density Polyethylene with 1% cSBS
H4B1	4% Recycled High Density Polyethylene with 1% cPB
L2S1	2% Recycled Low Density Polyethylene with 1% cSBS
L2B1	2% Recycled Low Density Polyethylene with 1% cPB
P2S1	2% Recycled Polypropylene with 1% cSBS
P2B1	2% Recycled Polypropylene with 1% cPB

Five different type polymers were used in this experimental work. Each with different level and dosages, three are recycled polymer and their notations begin with “r” on the other hand the notation for the commercial polymer starts with “c”.

Experimental design setup showing all blend combination is presented there in Table 3-3. On the other hand Table 3.4 shows some important notation for samples that has been used in this research.

Table 3-3: Experimental Design Setting of various blend combination

RPW Type	RPW Content	Commercial Polymer (SBS)				Commercial Polymer (PB)			
		0%	1%	1.5%	2%	0%	1%	1.5%	2%
rLDPE	0%	√	√	√	√	√	√	√	√
	2%	√	√	√	√	√	√	√	√
	4%	√	√	√	√	√	√	√	√
	6%	√	√	√	√	√	√	√	√
rHDPE	0%	√	√	√	√	√	√	√	√
	2%	√	√	√	√	√	√	√	√
	4%	√	√	√	√	√	√	√	√
	6%	√	√	√	√	√	√	√	√
rPP	0%	√	√	√	√	√	√	√	√
	2%	√	√	√	√	√	√	√	√
	4%	√	√	√	√	√	√	√	√
	6%	√	√	√	√	√	√	√	√

3.3 Preasoaking of Material

Recycled polymer were collected, cleaned and extruded and then one hour pre-soaking of polymer inside the asphalt was performed to allow the polymer to be soaked before blending.

3.4 Preparation of Polymer-Asphalt Blends

For this particular task, a special high shear mechanical blender with a shear speed of up to 3500 rpm was used. Figure 3.6 shows that mechanical shear blender. This is necessary given the fact that, most recycled plastic waste (RPW) are much difficult to blend with asphalt binder than the usual polymer. This is because some of these RPW have higher density and melting point than the usual conventional commercial polymers.

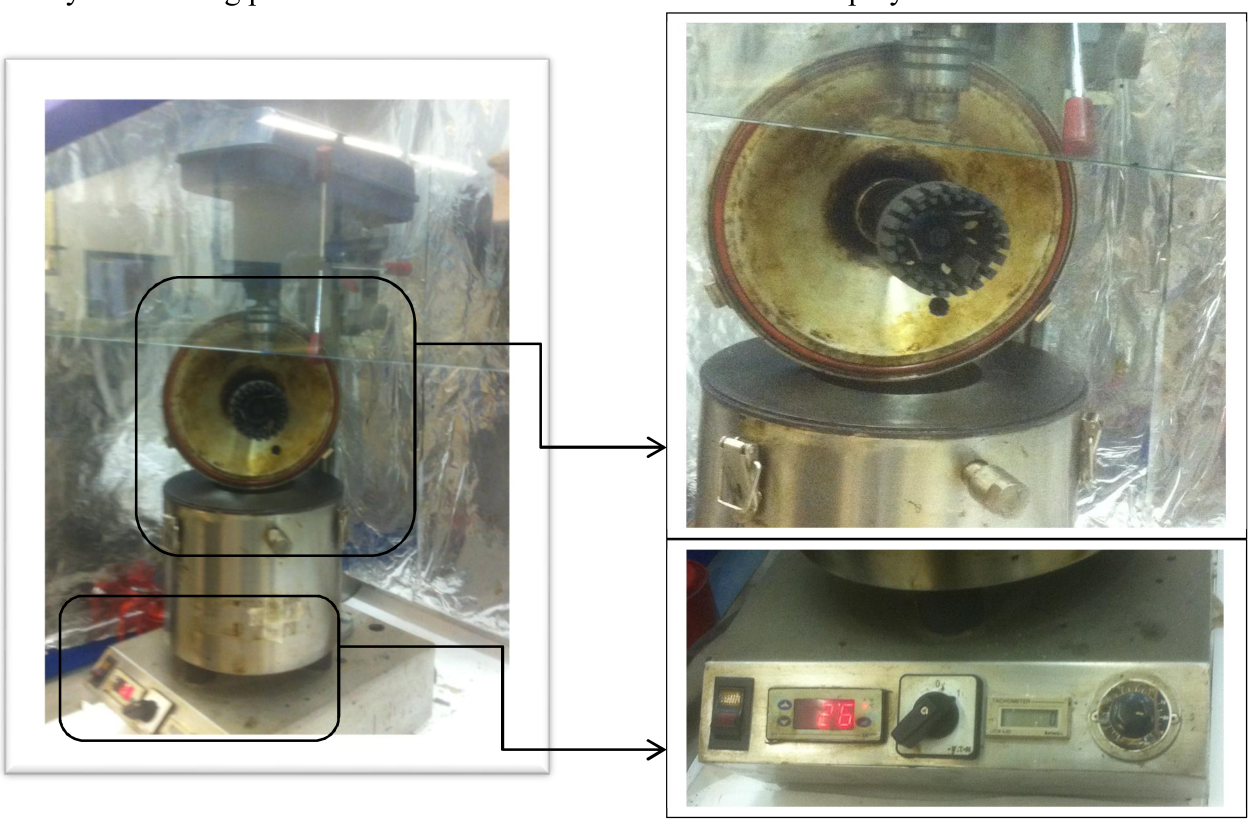


Figure 3.6: High speed Shear mechanical blender

Table 3-3 shows the general experimental design setting of various blend combination. Following two stages show the process for getting the successful and appropriate blends.

3.4.1 Optimization of the Blending Time:

For long time blending, it will definitely cause polymer agglomeration (Fang et al. 2014), oxidation (Fang, et al. 2009), additionally it is uneconomical and detrimental to the rheological properties of the modified binder (Brule et al. 1988). Furthermore the associated energy cost will be tremendous when this proposed blending method (blending for long time) is to be adopted for a large scale construction project. So this study determined optimum blending time of recycled LDPE, HDPE and PP. At the time of blending close observation of consistency of polymer modified asphalt was carried out, complex shear modulus ($G^*/\mathrm{Sin}\delta$) at 70ºC was used as measuring tools. $G^*/\mathrm{Sin}\delta$ values were taken at different time interval (@ 10, 20, 30, 40, 50, 60, 70 minute). The time needed to get the steady complex shear modulus ($G^*/\mathrm{Sin}\delta$) was taken as optimum blending time for that particular recycle polymer. Figure 3.6 represent typical graph for the determination of optimum blending time.

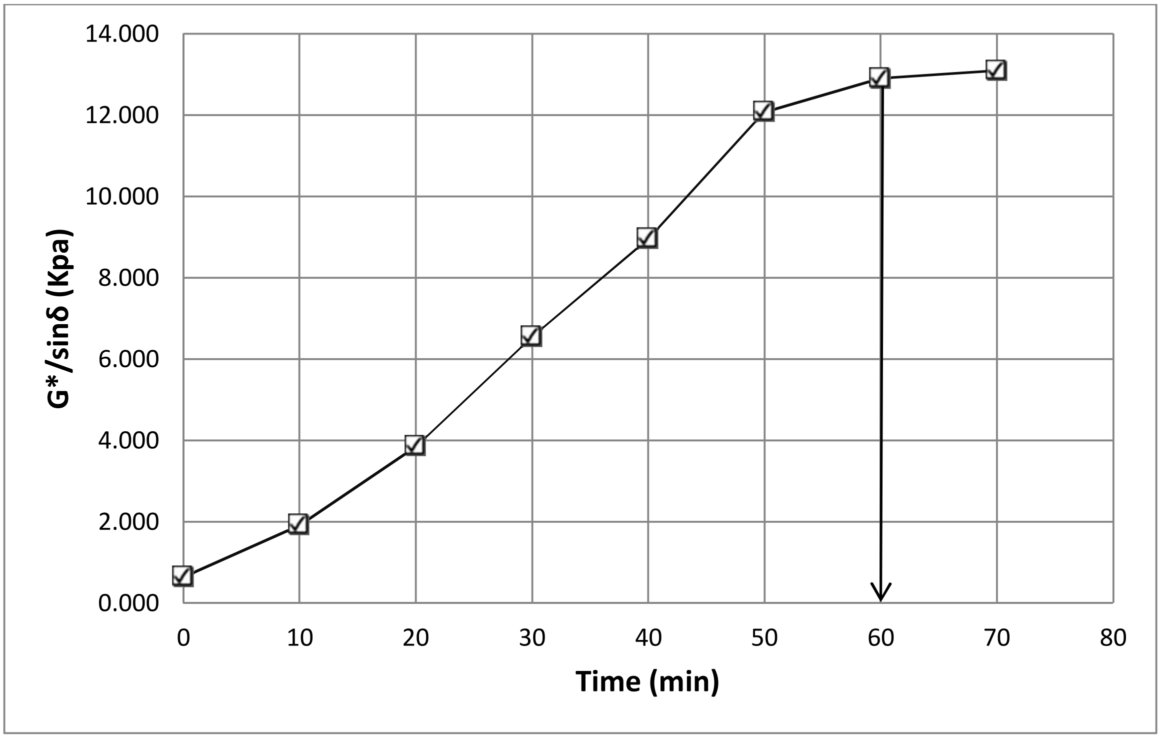


Figure 3.7: Determination of Optimum blending time

3.4.2 Preliminary Mixing of the RPW with the Binder

Various duration of mixing each particular waste with the binder was explored, until an optimum mixing time is achieved. When a poor blending is observed, the mixing conditions such as the mixing duration and temperature at the highest possible speed of the shear mixer were adjusted to the optimum level. Pre-soaking of polymer in the asphalt binder for one hour duration was done of at relatively lower temperature. This facilitates easier mixing in the shortest time duration. Hence eliminating the risk of excessive aging/oxidation of the binder, and minimizing the required mixing energy.

3.5 Experimental Testing

The viscoelastic performance and physical and rheological properties of the selective aged and un-aged blends at various dosage of the RPW in combination with SBS and polybilt were investigated. Series of tests were conducted and their standard procedure requirements are mentioned below.

3.5.1 Flash Point and Fire Point Test

This test was conducted as per specification of ASTM D 92 to evaluate the characteristics of the modified asphalt materials in response to heat and a test flame under laboratory conditions. As we are adding different recycled and commercial polymer material so we had therefor performed this test to be sure about the safety and condition of fire hazard or fire risk under true fire conditions.

3.5.2 Rotational Viscosity Test (ASTM D 4402)

This test was performed for all the samples to evaluate the apparent viscosity of asphalt at 135°C using a rotational viscometer and a temperature-controlled thermal chamber for maintaining the test temperature. This test is one of the SHRP specified test to check the constructability and handling requirement of the asphalt. Figure 3.8 shows the viscometer used in this experiment,

Figure 3.8: Brookfield Rotational Viscometer

3.5.3 Rolling Thin Film Oven Test (ASTM D2872 - 12)

This test was carried out for the entire sample as a part of SHRP specified test to estimate the consequence of heat & air on a moving film of modified and pure asphaltic materials. The outcomes of this test are dictated from evaluations of the nominated characteristics of the asphalt before and after the test.

Figure 3.9: Rolling thin FIlm Oven Test equipment

Samples were prepared and placed inside the rack and tested at 163°C for 85 minutes Figure 3.9 shows RTFO equipment used in this research.

3.5.4 Dynamic Shear Rheometer Test (ASTM D6521 - 13)

This test was done for the control binder and modified binder to characterize the viscous and elastic behaviour of asphalt binder at service temperature. Complex shear modulus and evaluation of rutting and fatigue parameter are major outcomes of this test. Figure 3.10 shows dynamic shear rheometer equipment.

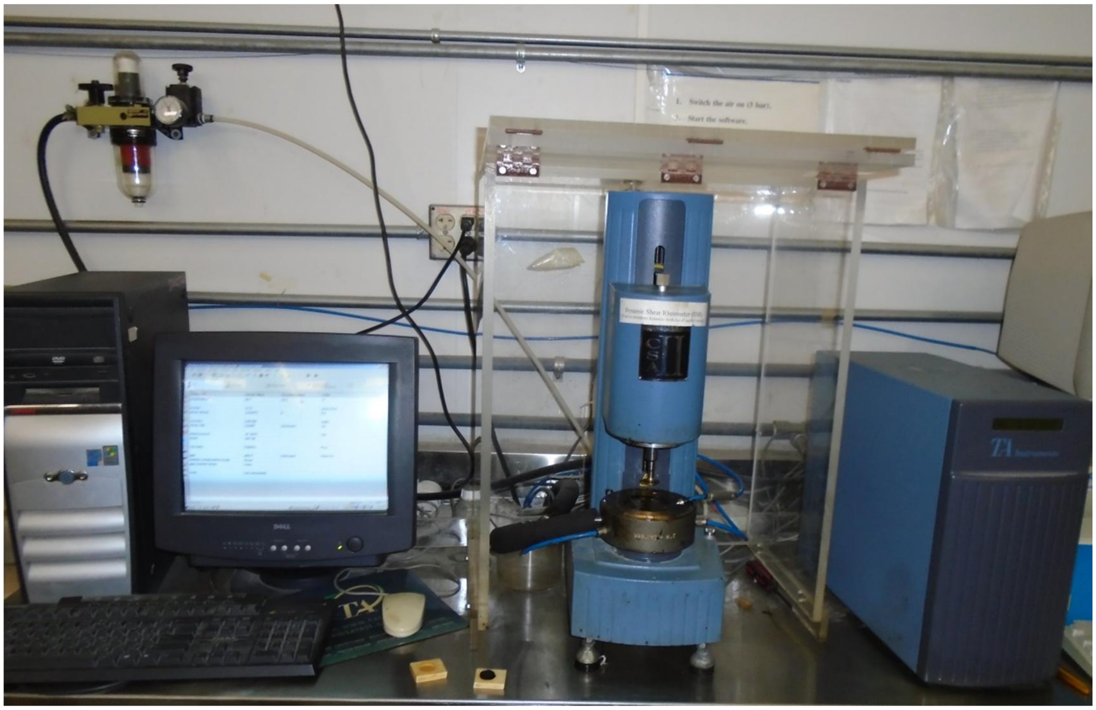


Figure 3.10: Dynamic Shear Rheometer equipment

3.5.5 Determination of Performance Grading of Modified Binder

The resulting RPW and SBS-RPW and SBS-polybilt modified asphalt were classified in accordance to the Superior Performing Asphalt Pavements' system (super-pave) of Strategic Highway Research Program (SHRP) of the United States.

3.6 Data Analysis

The obtained experimental data was analysed, statistical techniques such as analysis of variance (ANOVA) was employed to determine the most significant factors and most prominent modifier for improvement of the upper performance grade (UPG) of the asphalt. Factorial design was performed to get the main and interaction effects of different modifiers of asphalt used in this experimental work.

3.7 Methodology and Material Processing Flow Chart

A concise chart in Figure 3.11 shows recycled material processing steps and Figure 3.12 displays synopsis of the research work including all major tasks and experiments for the fulfilment of objective.

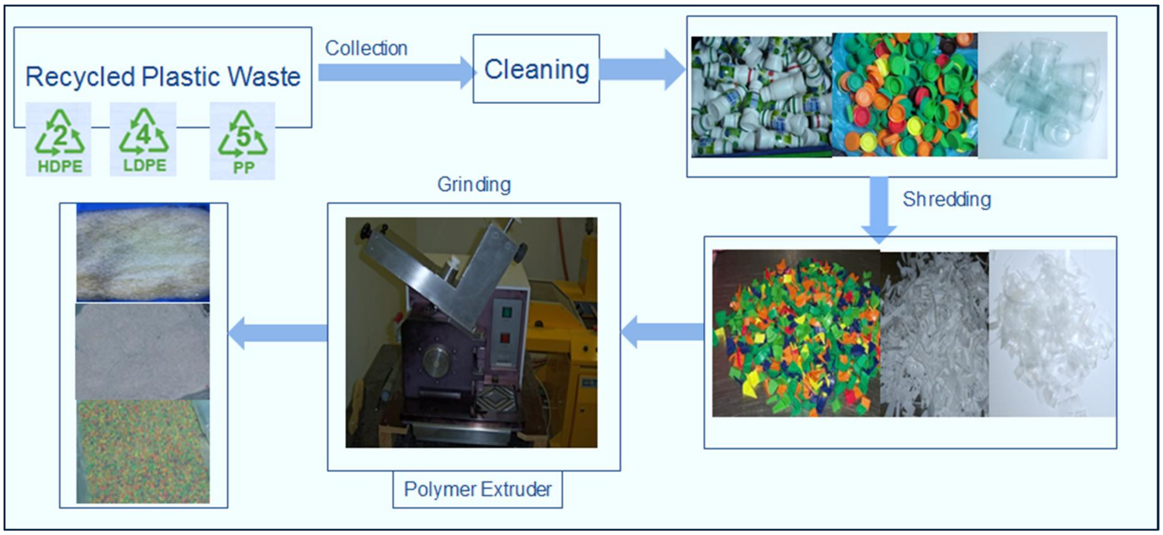


Figure 3.11: Recycled Material Processing Steps

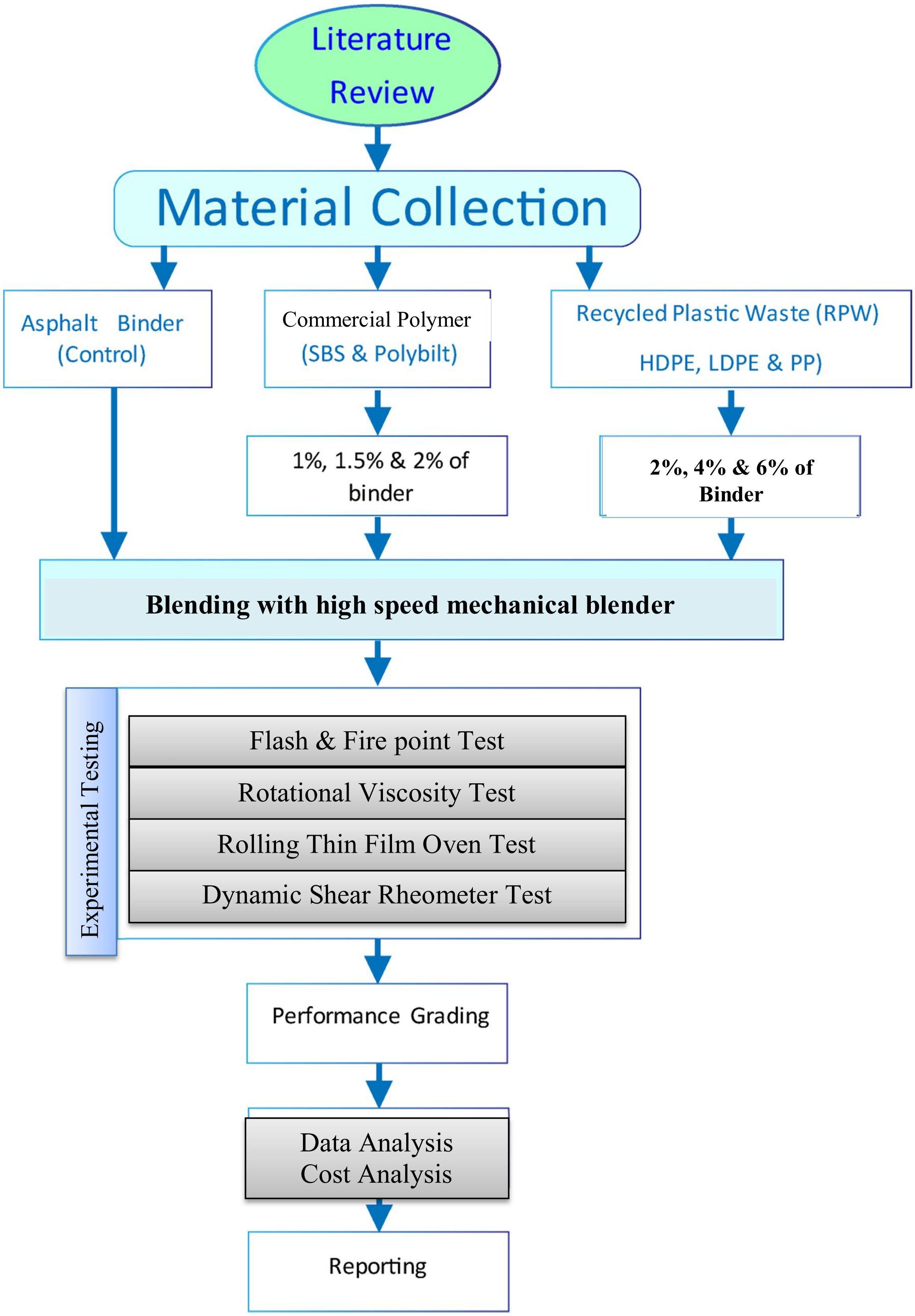


Figure 3.12 : Flowchart Showing Research Methodology

CHAPTER 4

RESULTS AND DISCUSSION

This chapter describes laboratory test results within this study, analysis and relevant discussions. Moreover it covers elaborate discussions about potential recycled plastic waste and determines optimum dosages of recycled LDPE, HDPE and PP combined with commercial polymers (SBS and polybilt). A comparative cost analysis was also presented and finally ANOVA analysis was discussed.

4.1 Determination of Blending Temperature

To specify blending temperature of each of the polymers their melting temperature is needed. Finding melting temperature for the commercial polymers (SBS and Polybilt) were easy but for the recycled polymers (LDPE, HDPE and PP), Differential Scanning Calorimetry (DSC) test was used to get melting temperature. Figure 4.1, 4.2 and 4.3 represent DSC result of HDPE, LDPE and PP. As it can be observed that melting point for rHDPE is 130^{o}C. For rLDPE (Figure 4.2) it was found 110^{o}C. For recycled PP almost 160^{o}C was found as the melting temperature. To obtain blending temperature a buffer of 50^{o}C was added for LDPE and HDPE and 30^{o}C was added for PP with their corresponding melting point.

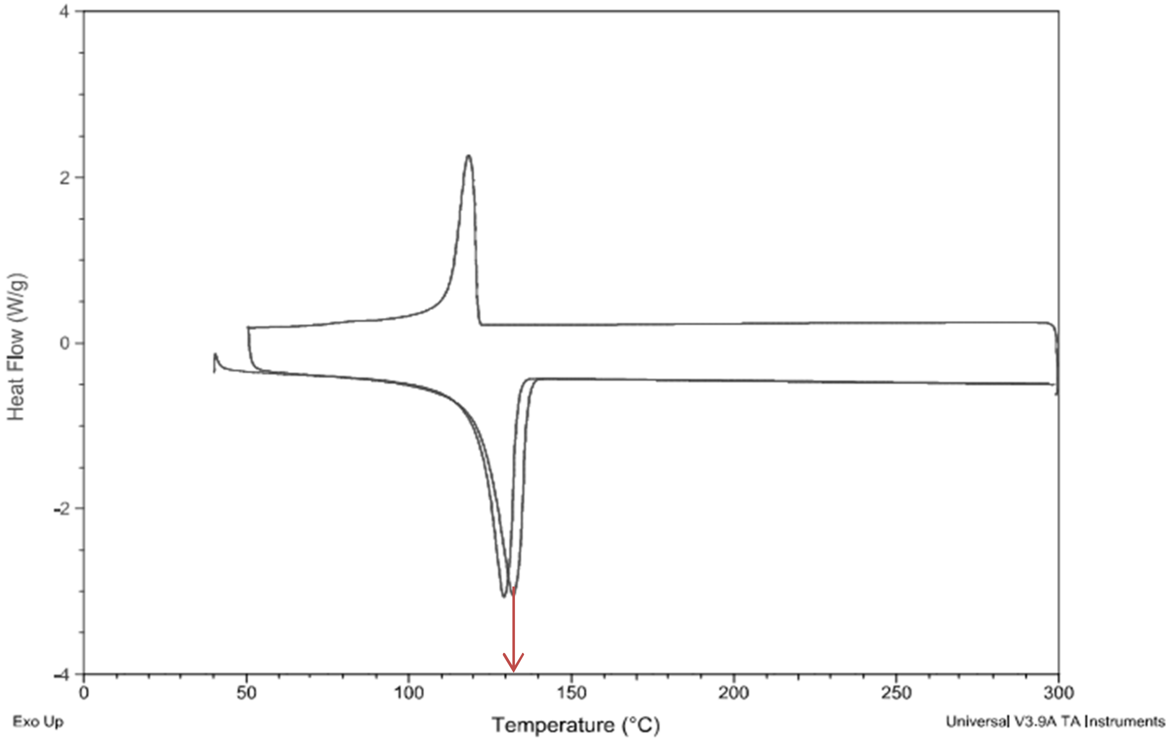


Figure 4.1: DSC result of rHDPE

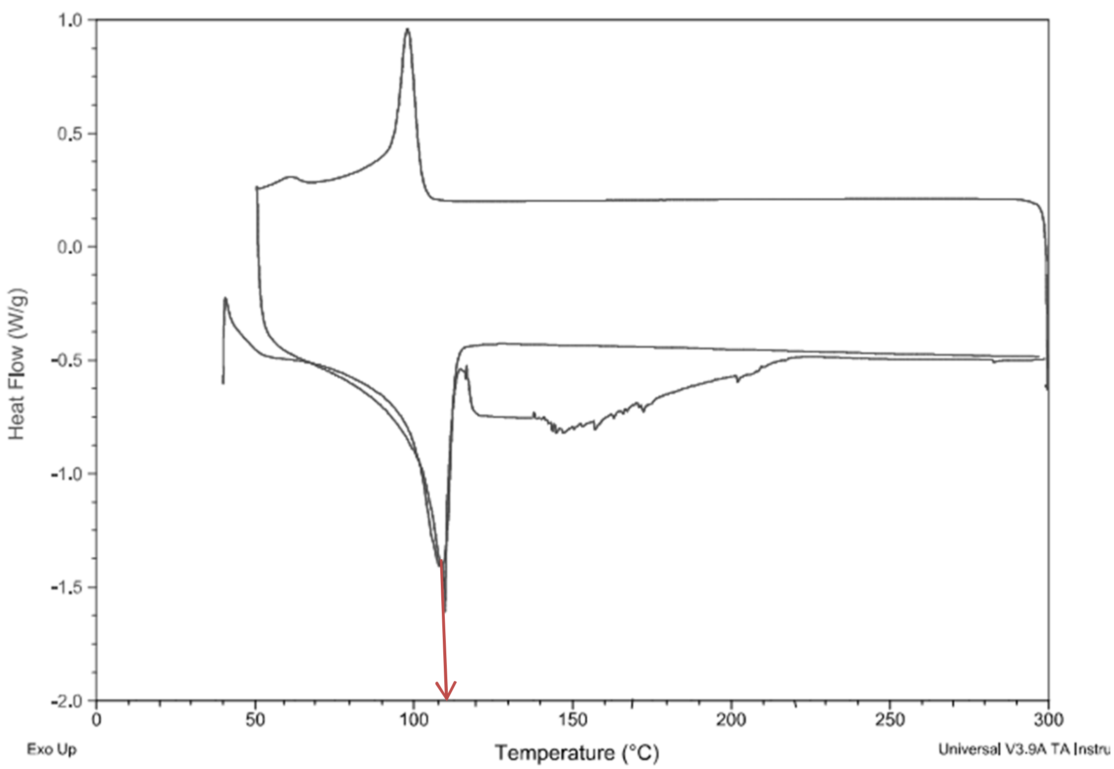


Figure 4.2: DSC result of rLDPE

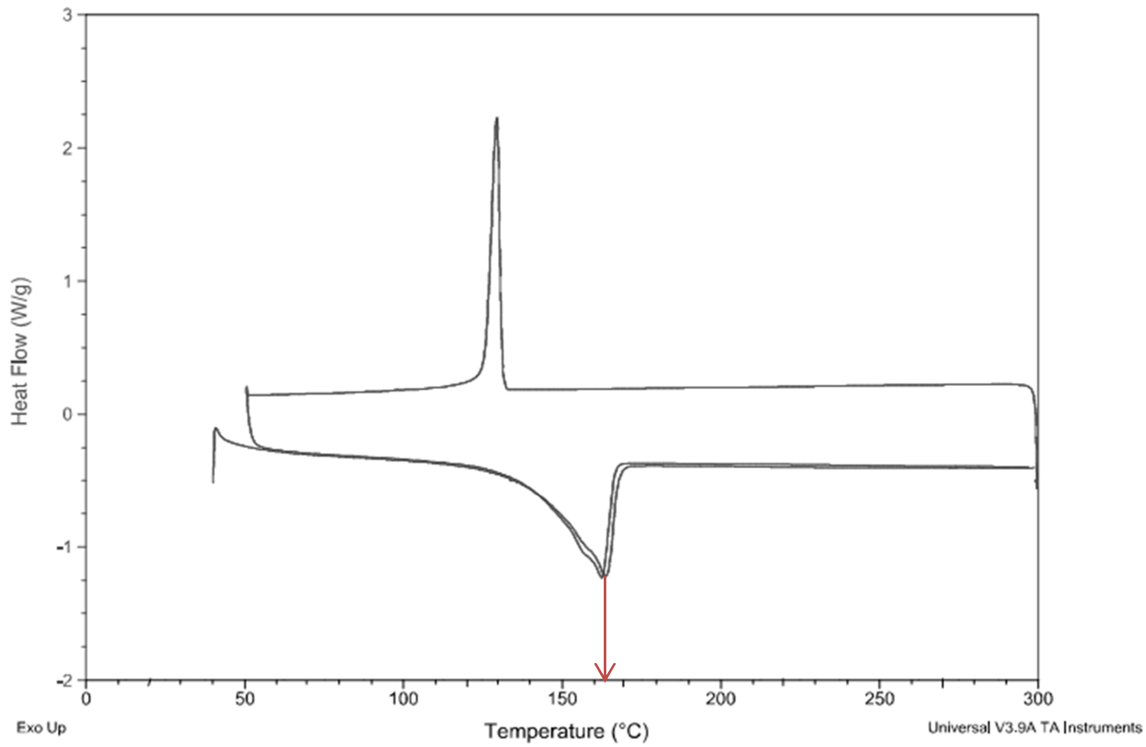


Figure 4.3: DSC result of rPP

Table 4-1: Blending Temperature of Recycled Polymer

Polymer Name	Melting Point (°C)	Blending Temperature(°C)	Recycle Symbol	Sample Code
rLDPE	110	160	♶	L
rHDPE	130	180	♴	H
rPP	160	190	♷	P

4.2 Determination of Optimum Blending Time

Optimum Blending Time was determined by blending some trial blends using 4% of each of the recycled polymers at different time intervals (10, 20, 30, 40, 50, 60, 70 minute) and their G*/ Sinδ (complex shear modulus) were determined. G*/ Sinδ verses time for each recycled polymer was graphically represented in the Figure 4.4, 4.5 and 4.6. It has been observed that adding recycled polymer to control binder shows molecular association and as soon as the dispersion of polymer becomes uniform the G*/ Sinδ (complex shear modulus) values becomes stable over time.

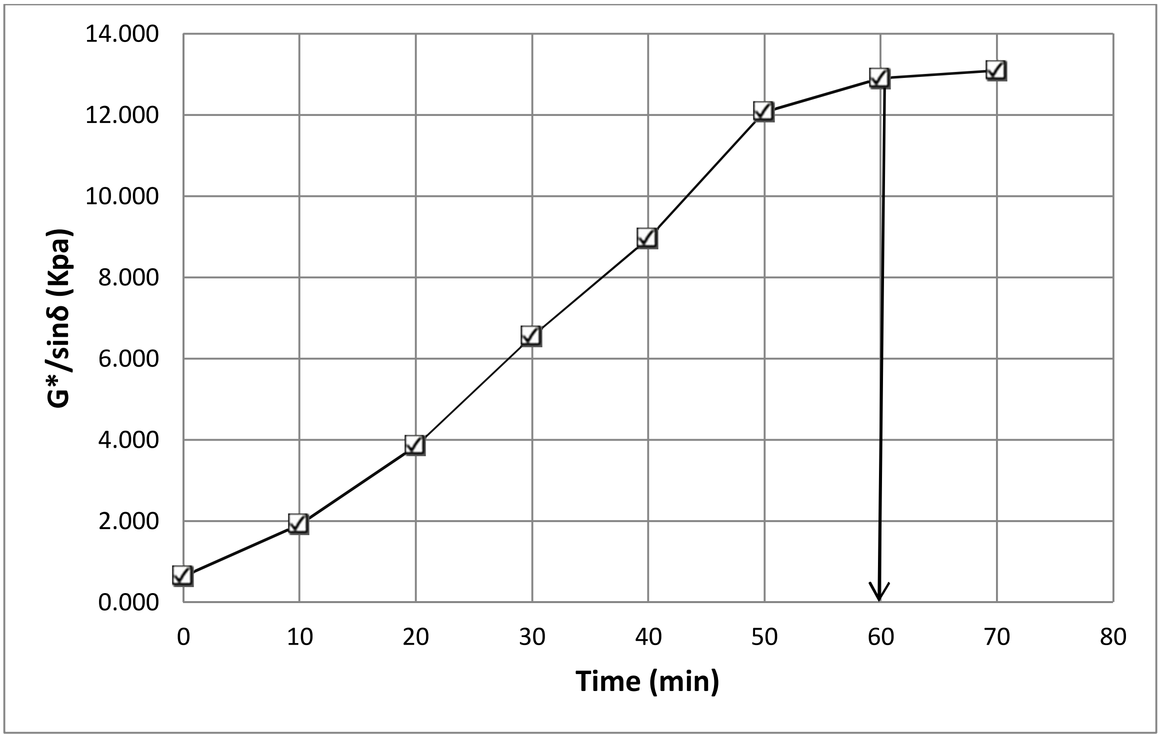


Figure 4.4: Optimum Blending Time for rHDPE

Closely observing Figure 4.4 it has been found that optimum blending time for rHDPE can be identified as 60 minutes. Similarly from Figure 4.5, 30 minutes can be identified as blending time of rLDPE.

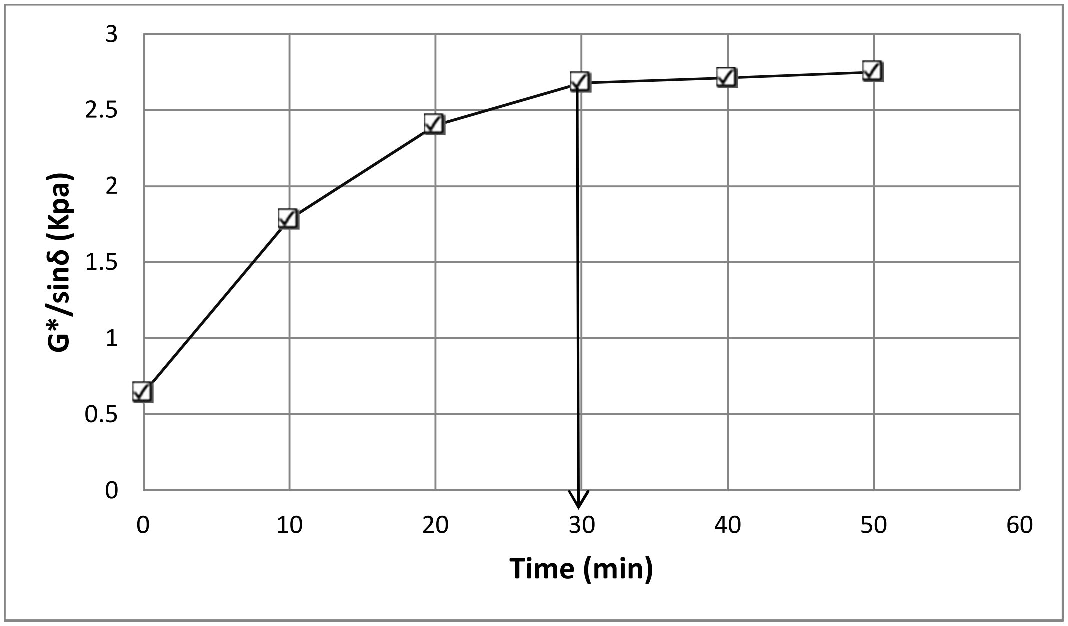


Figure 4.5: Optimum Blending Time for rLDPE

From Figure 4.6 it is clear that for rPP after 50 minutes blending time G*/ Sinδ values reach to almost a constant value, So optimum blending time for rPP was taken as 50 minutes.

Blending temperature and time for commercial polymers were found from some previous study (K.J. Adham, 2014) and from supplier's manuals. Blending temperature and Optimum Blending Time (OBT) for commercial and recycled material used in this research, are presented in Table 4-2,

Table 4-2: Blending temperature and duration of selected polymer

Material	Melting Temperature (^{o}C)	Blending Temperature (^{o}C)	Blending Time (Minute)
rLDPE	110	160	30
rHDPE	130	180	60
rPP	160	190	50
cSBS	-	180	60
cPB	-	145	60

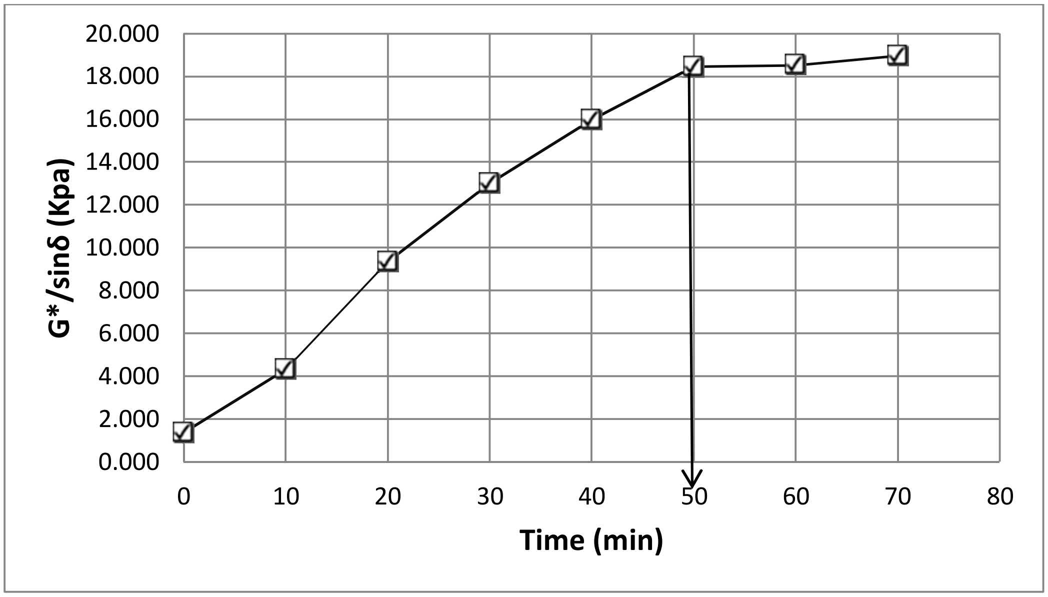


Figure 4.6: Optimum Blending Time for rPP

For the combination of recycled polymer with commercial polymer the critical blending time and blending temperatures were used to ensure homogeneous blending. For example rLDPE has blending temperature of 160°C. On the other hand cSBS has a blending temperature of 180°C. Maximum of these two values, which is 180°C, was taken as blending temperature of rLDPE+cSBS combined blend. Similarly critical blending temperature for all combined (recycled & commercial polymer) blends were determined and showed in Table 4-3.

Table 4-3: Blending duration and Temperature for combined blend

Material	Blending Temperature (°C)	Blending Time (Minute)
rLDPE+cSBS	180	60
rHDPE+cSBS	180	60
rPP+cSBS	190	60
rLDPE+cPB	160	60
rHDPE+cPB	180	60
rPP+cPB	190	60

4.3 Rheological Properties and Upper Performance Grade (UPG)

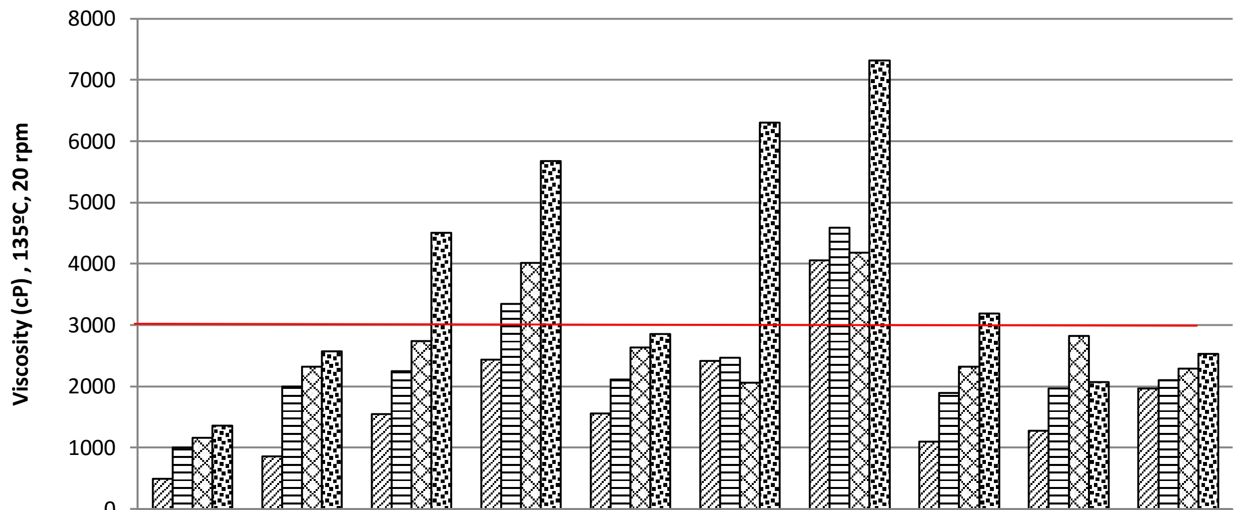
Rheology of control binder and modified binder has been tested over a wide range of temperatures. Addition of recycled and commercial polymer and their rheological response are described in the following sub sections.

4.3.1 Rotational Viscosity Test Result of Modified Bitumen

Viscosity is one of the key rheological properties of the binder which is basically the ability to flow at higher temperature and these properties ensure adequate pumping and mixing with aggregate. At low temperature bitumen shows elastic behaviour, however at high temperature it behaves like a viscous material. This study inspected the viscosity of control and modified binder at production and working temperature (135^{o}C).

Figure 4.7 illustrates rotational viscosity result at 135^{o}C of three different recycled polymers (HDPE, LDPE & PP) with four different contents (0%, 2%, 4% and 6%) of each, interacting with four different dosages (0%, 1%, 1.5% and 2%) of commercial SBS. Units are measured in cP (centipoise).

In terms of varying contents (from 0% to 2%) of SBS with no recycled polymer nominal enhancement of viscosity was found. For example for control binder (0% SBS), the viscosity was around 500cP. Addition of 1%, 1.5% and 2% SBS increased the viscosity to almost 1000, 1170 and 1370 cP respectively. This inclusion of 2%, 4% and 6% rLDPE shows increasing trend, which can be clearly perceived from Figure 4.8. LDPE molecule with asphalt forms such a network that increased internal resistance to flow at 6% rLDPE this resistance is most dominant.



	0% PW	2 % rLDPE	4%rLDPE	6%rLDPE	2% rHDPE	4% rHDPE	6% rHDPE	2% rPP	4% rPP	6% rPP
0% SBS	500	862.5	1558	2446	1563	2425	4063	1113	1288	1975
1% SBS	1010.5	2009.72	2256	3360.5	2127.22	2478.78	4601.3	1898.8	1974.00	2115
1.5% SBS	1173.59	2326.5	2749.5	4029.78	2645	2068	4196	2326.5	2832.22	2303
2% SBS	1374.28	2585	4512	5687	2867	6310.22	7332	3200	2080.22	2535.86

Figure 4.7: Viscosity result of asphalt modified with Recycled Polymer & SBS

From Figure 4.8, a gradual viscosity increasing trend has been observed. This rate of increment is quite higher for 6% LDPE blends. The difference between viscosity of 6% HDPE blends with 4% LDPE blends are more than that of between 2% LDPE blends with 4% LDPE blends, this is because of presence of more LDPE network contribute to increase flow resistance.

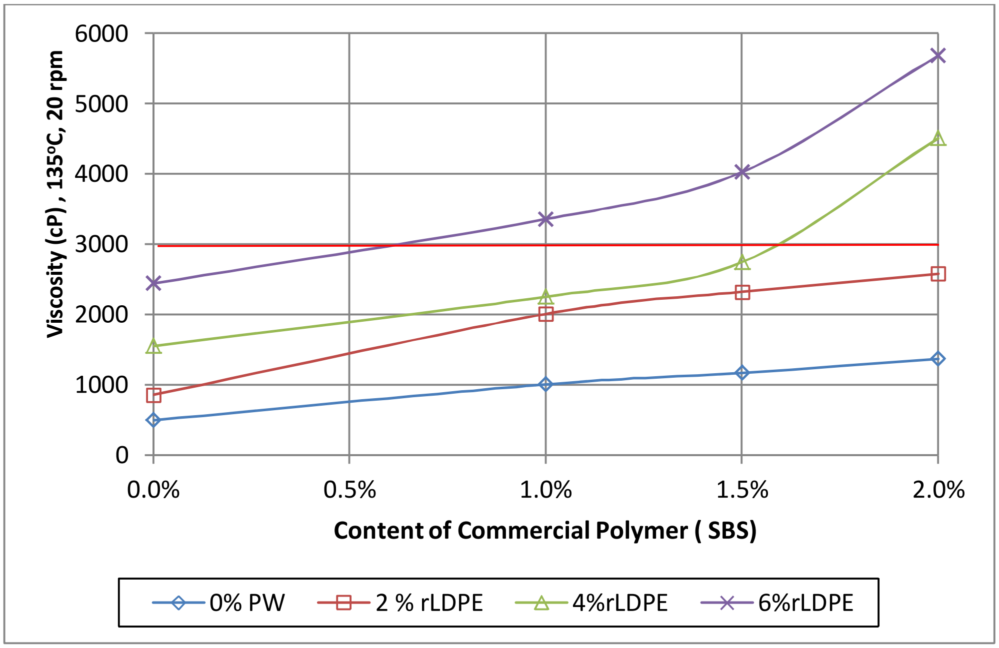


Figure 4.8: Viscosity result of asphalt modified with Recycled LDPE & SBS

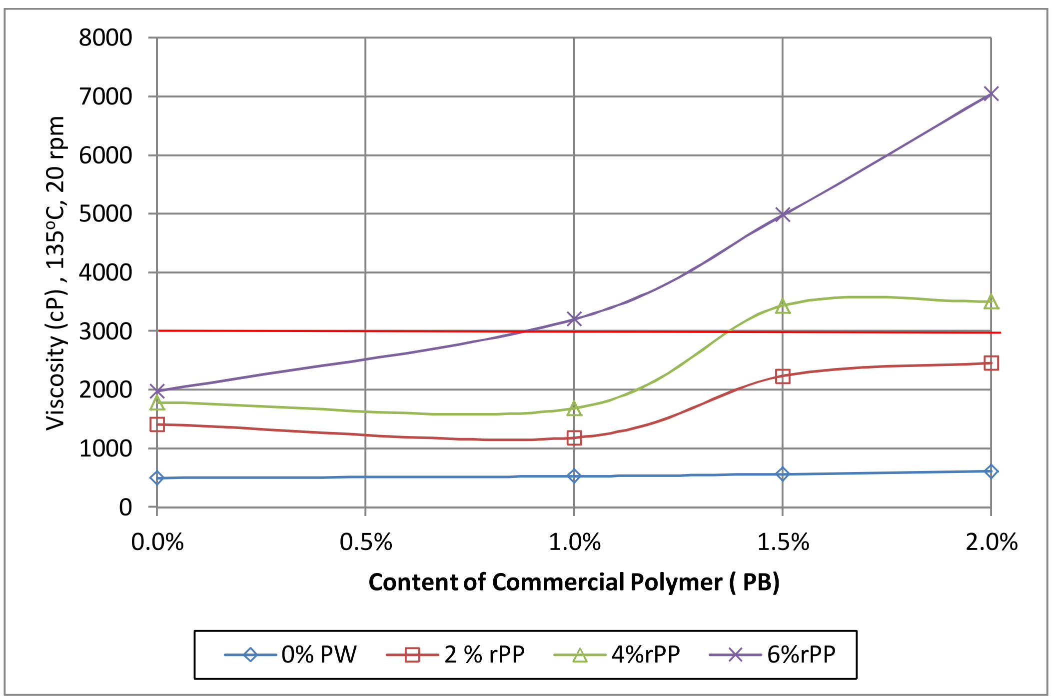
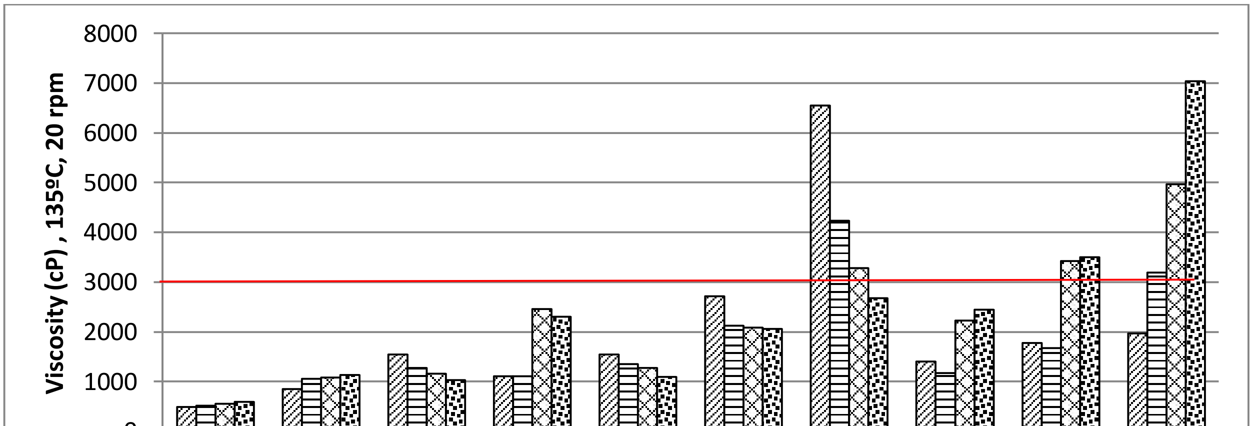


Figure 4.9:Viscosity result of asphalt modified with Recycled PP & commercial PB

Polybilt alone can improve the viscosity slightly (Figure 4.9) however adding polypropylene accelerated the increment. It is also noticeable that 6% PP with the addition of more than 1% PB in asphalt yields such a high viscosity that exceeds the SHRP specified viscosity limit (3000cP).

Figure 4.10 shows viscosity results of asphalt modified with different recycled polymers and polybilt. The obvious trend has been observed that polybiltd slightly improves viscosity while only polybilt is used as modifier by looking at the first cluster (0% PW) one can easily perceive that.



	0% PW	2 % rLDPE	4 % rLDPE	6 % rLDPE	2 % rHDPE	4 % rHDPE	6 % rHDPE	2 % rPP	4 % rPP	6 % rPP
0% PB	500	862.5	1563	1113	1563	2725	6563	1413	1788	1975
1% PB	528.75	1069.72	1280.28	1116.72	1362	2138	4250	1188	1688	3204
1.5% PB	566.35	1092	1166.72	2466.72	1288	2100	3300	2237	3438	4982
2% PB	611	1139.28	1043.4	2314.28	1110	2073	2688	2462	3512	7050

Figure 4.10: Viscosity result of asphalt modified with Recycled Polymer & Polybilt

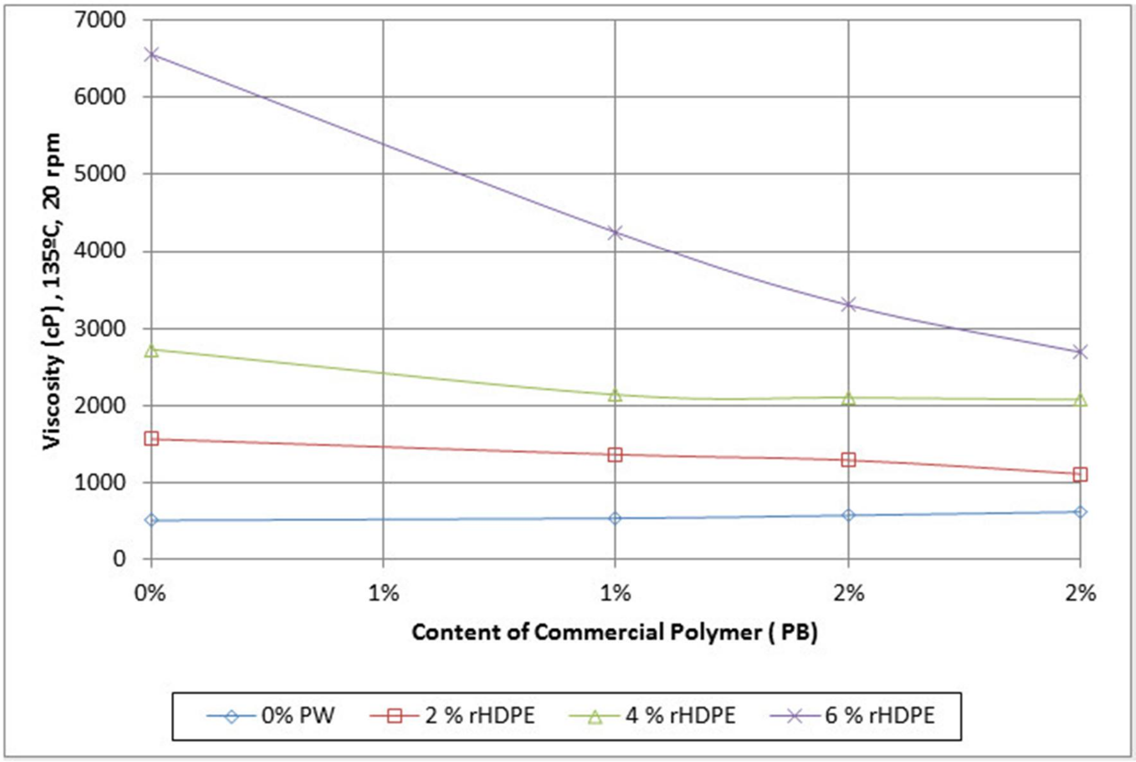


Figure 4.11: Viscosity result of asphalt modified with Recycled HDPE & Polybilt

Recycled PP at 2%, 4% and 6% contents along with polybilt shows continuous increment of viscosity however for rHDPE + Polybilt (Figure 4.11) blend, decreasing trend is found. For rHDPE and polybilt blend, rHDPE asphalt network increases the flow resistance and intermolecular friction. On the other hand polybilt–asphalt network seems to be shear thenning and reduces intermolecular friction in some extent. This is because flow resistance capacity of HDPE-asphalt is more dominant than that of polybilt-asphalt.

Those changes of viscosity of different polymer combination can be interpreted as the thickening or thinning effect of each particular polymer. Viscosity can be termed as function of polymer structure and formation of polymer network inside asphalt matrix, this is also supported by the study of Saeed Sadeghpour Galooyak in 2010 (Galooyak et. al 2010) and Romero Santos Fernandes (Fernandes et. al 2008).

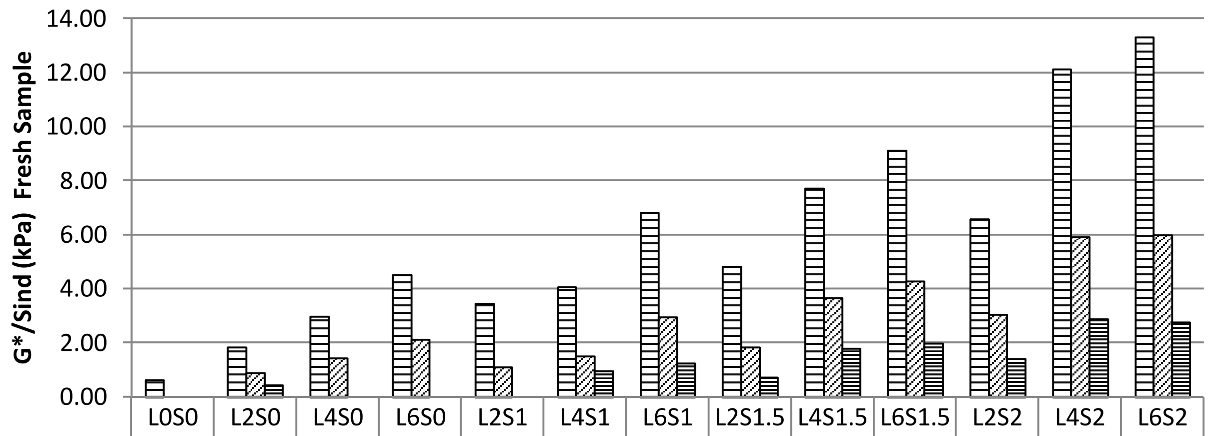
From the observations of viscosity results of all blends it can be concluded that LDPE and SBS together have shear thickening effect and this effect becomes dominant at the presence of more polymer network. LDPE and polybilt also have thickening effect at lower LDPE content but at higher content this effect becomes minor.

Based on SHRP specifications, viscosity should be below 3000cP at 135^{o}C. Four blends with LDPE (L4S2, L6S1, L6S1.5, L6S2), 6 blends with HDPE (H6S1, H6S1.5, H6S2, H6B1, H6B1.5 & H6) and 6 blends with PP (P2S2, P4B1.5, P4B2, P6B1, P6B1.5 & P6B2) do not pass SHRP viscosity specifications.

4.4 Rutting Resistance at High Temperature

Rutting is one of the vital distresses associated to high temperature and overloading. The rutting parameter ($G^*/Sin\delta$) of different blends of recycled HDPE with commercial SBS was displayed at different test temperatures and improvement of rutting resistance of modified asphalt has been represented here for RTFO condition and for the fresh sample.

Figure 4.12 (Fesh sample) and 4.13(RTFO sample) illustrates $G^*/Sin\delta$ values at 70^{o}C, 76^{o}C and 82^{o}C temperature for control binder and for rLDPE and cSBS modified binder analyzed with the DSR. All samples of rLDPE with cSBS show significant improvement of rutting resistance for both aged and un-aged condition. Addition of rLDPE and cSBS raised the stiffness of the control binder thus extended the range of service temperature.

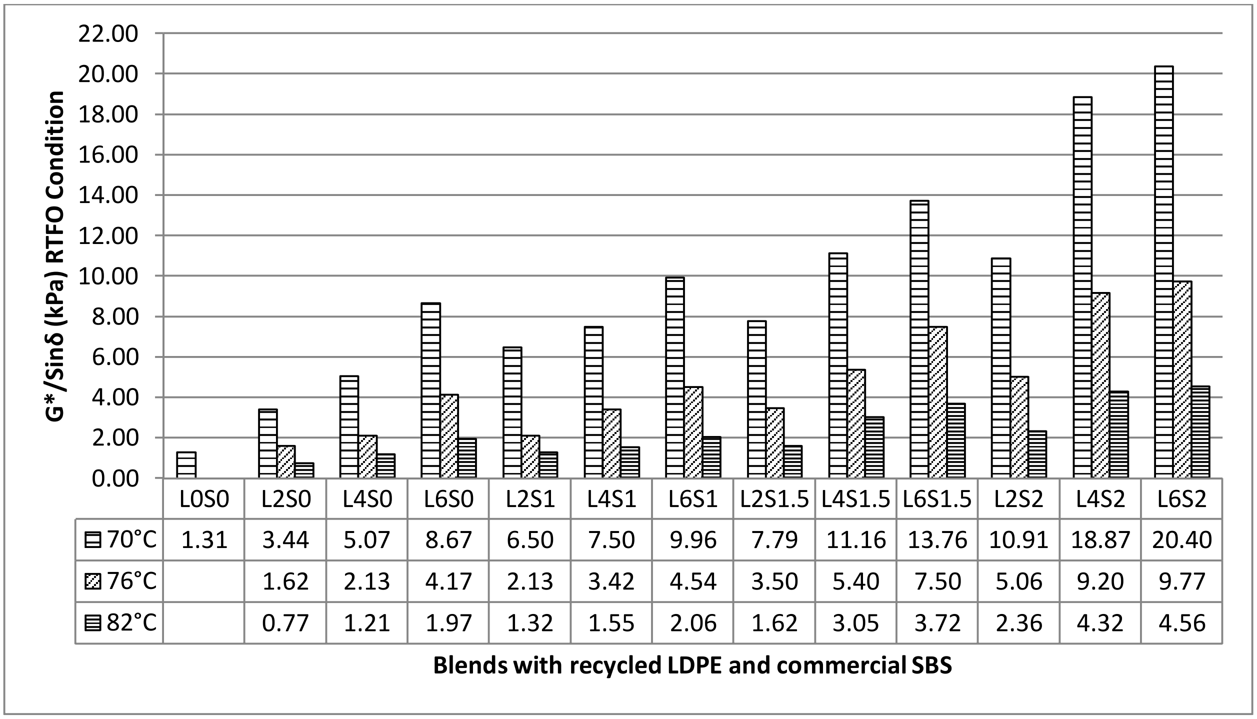


	L0S0	L2S0	L4S0	L6S0	L2S1	L4S1	L6S1	L2S1.5	L4S1.5	L6S1.5	L2S2	L4S2	L6S2
70°C	0.64	1.85	2.99	4.53	3.45	4.08	6.81	4.82	7.73	9.12	6.58	12.14	13.32
76°C		0.89	1.43	2.12	1.10	1.50	2.97	1.83	3.66	4.29	3.05	5.91	5.99
82°C		0.43				0.96	1.25	0.72	1.80	1.98	1.42	2.88	2.75

Blends with Recycled LDPE and commercial SBS

Figure 4.12: Rutting resistance at high service temperature of PMB (Fresh Sample)

Closely observing the cluster of L2S0, L4S0 and L6S0 from bar diagram, it can be found that, 2% rLDPE improves the rutting resistance slightly more than the control binder, which means rLDPE molecules form network with asphalt molecule. This makes them stiffer to some extent. Adding another 2% also showed slight improvement thus height of L4S0 group is slightly higher than height of L2S0. However inclusion of another 2% with that 4% LDPE gives an accelerated increment. This dominant increment of resistance to permanent deformation is due to the thickening effect of LDPE molecules.



	L0S0	L2S0	L4S0	L6S0	L2S1	L4S1	L6S1	L2S1.5	L4S1.5	L6S1.5	L2S2	L4S2	L6S2
70°C	1.31	3.44	5.07	8.67	6.50	7.50	9.96	7.79	11.16	13.76	10.91	18.87	20.40
76°C		1.62	2.13	4.17	2.13	3.42	4.54	3.50	5.40	7.50	5.06	9.20	9.77
82°C		0.77	1.21	1.97	1.32	1.55	2.06	1.62	3.05	3.72	2.36	4.32	4.56

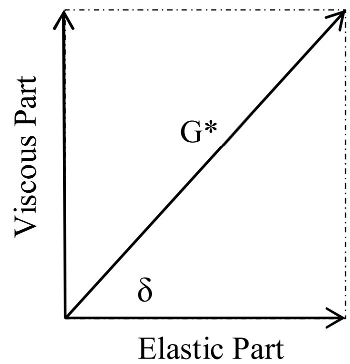
Figure 4.13: Rutting resistance at high service temperature of PMB (RTFO Condition)

Further comparison between clusters L6S0 (6% LDPE & 0% SBS) and L6S1 (6% LDPE & 1% SBS) shows that inclusion of 1% SBS increases rutting resistance a little at lower temperature and at higher temperature this increment becomes more insignificant.

Some other graphical results of different recycled and commercial polymer combination have been presented in Appendices.

4.4.1 Viscoelastic Component Analysis

The complex shear modulus G* calculated from DSR results are basically the total resistance of the binder to deformation at repeated shear load. This G* can be analysed in two components. These are elastic Part (horizontal portion of Figure: 4.14) and viscous part (vertical portion). As δ increases with constant G*, materials viscous part will also increase.



$$\tan\delta = \frac{Viscous\ Part}{Elastic\ part}$$

Figure 4.14: Complex Modulus Component

The tanδ can be a relative measure of visco-elasatic behaviour. From Figure 4.15 it can be observed that, with the increase of temperature viscous part becomes more dominant than elastic part.

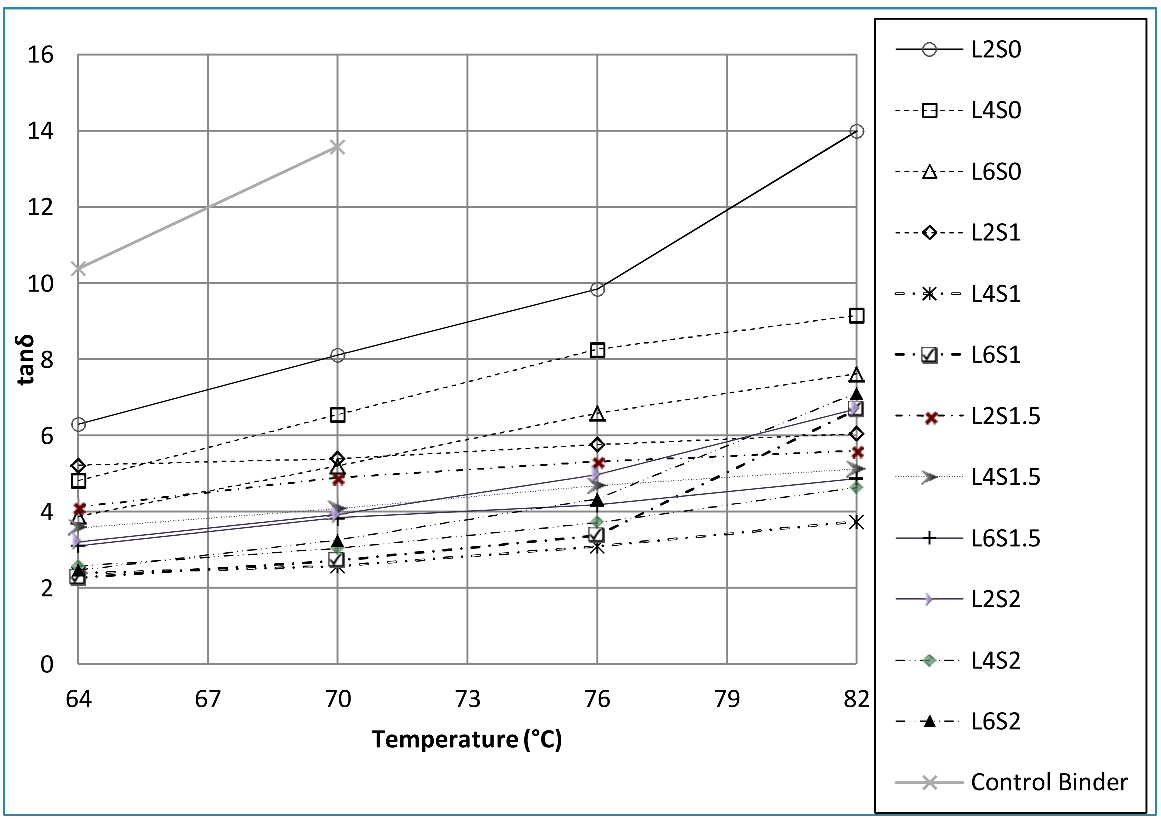


Figure 4.15 : Plots for tanδ vs. temperature

The rate was steeper at lower content of LDPE, for example tanδ line for L2S0 is steeper than L4S0. L4S0 and L6S0 have equivalent tanδ curve. Thus they have similar elastic responses. The line with samples L2S1 and L2S1.5 are flat and seems favourable. At higher temperature it indicates the presence of polymeric network with lower viscosity. Higher LDPE content with SBS shows comparatively less favourable than lower LDPE with SBS. The line for sample L4S2 and have almost equivalent shape and even at higher temperature the viscoelastic ratios do not change that much so those two blends are also more favourable in terms of viscoelastic performance.

4.5 Upper Performance Grade (UPG)

Based on SHRP binder performance specification a sample calculation to determine actual PG grade has been shown in Figure 4.16 and 4.17. Figure 4.16 shows DSR result for un-aged condition and figure 4.20 shows result for RTFO condition for the binder modified with 4% rLDPE and 1% SBS (sample L4S1)

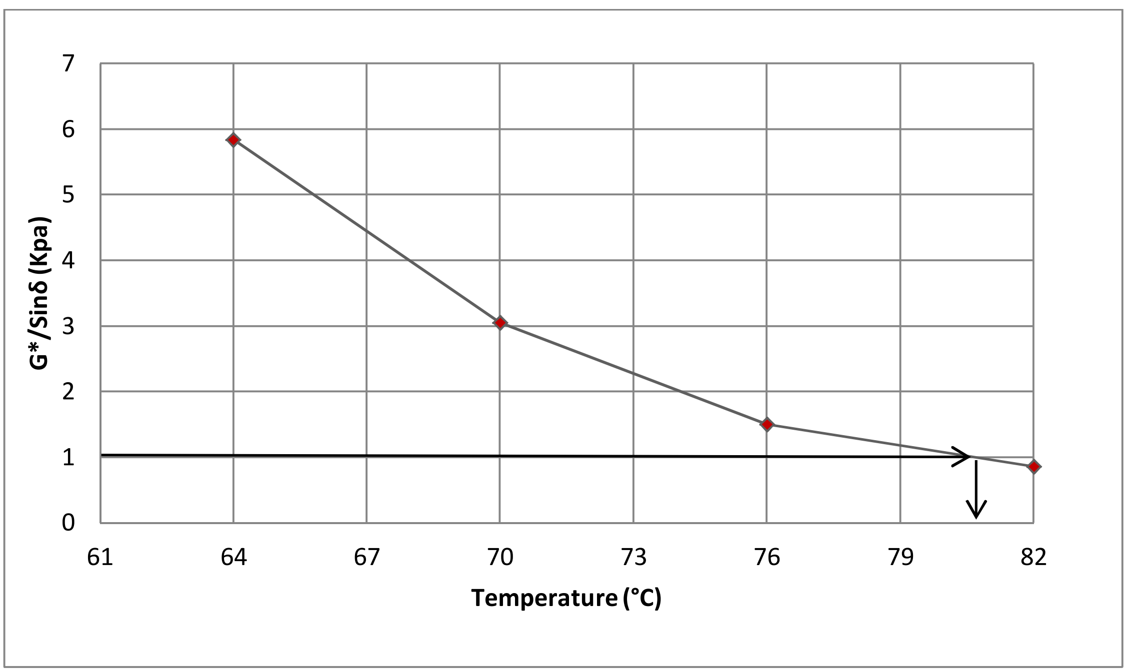


Figure 4.16: G*/Sinδ Values of 4% LDPE and 1% SBS Modified binder (Original Condition)

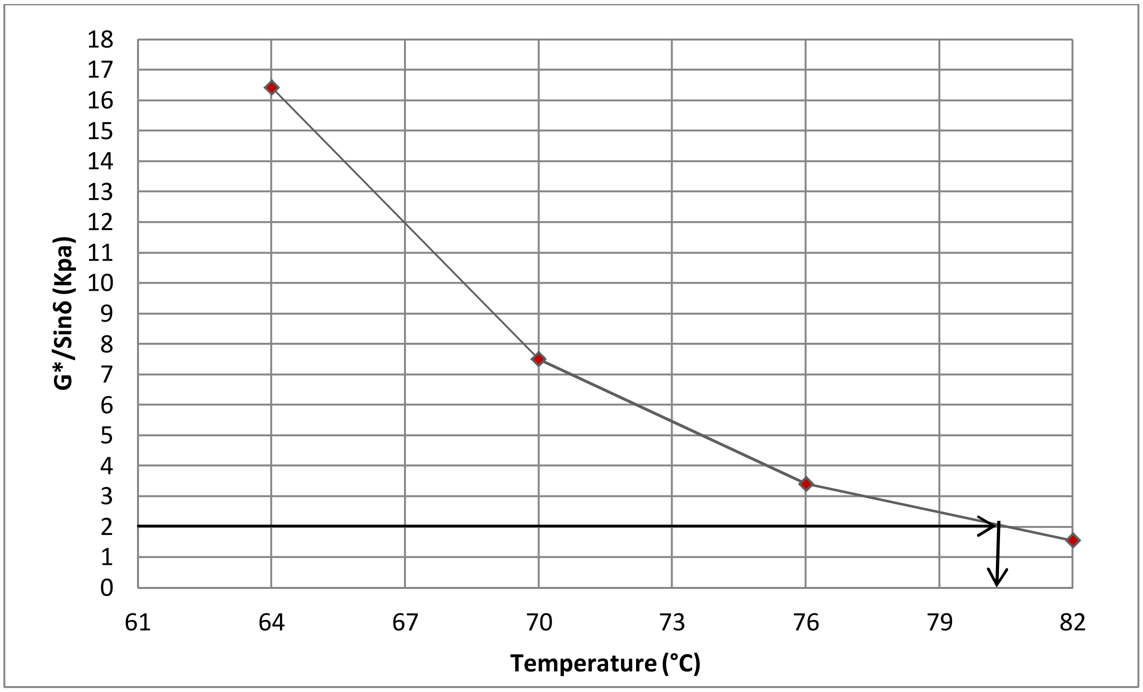


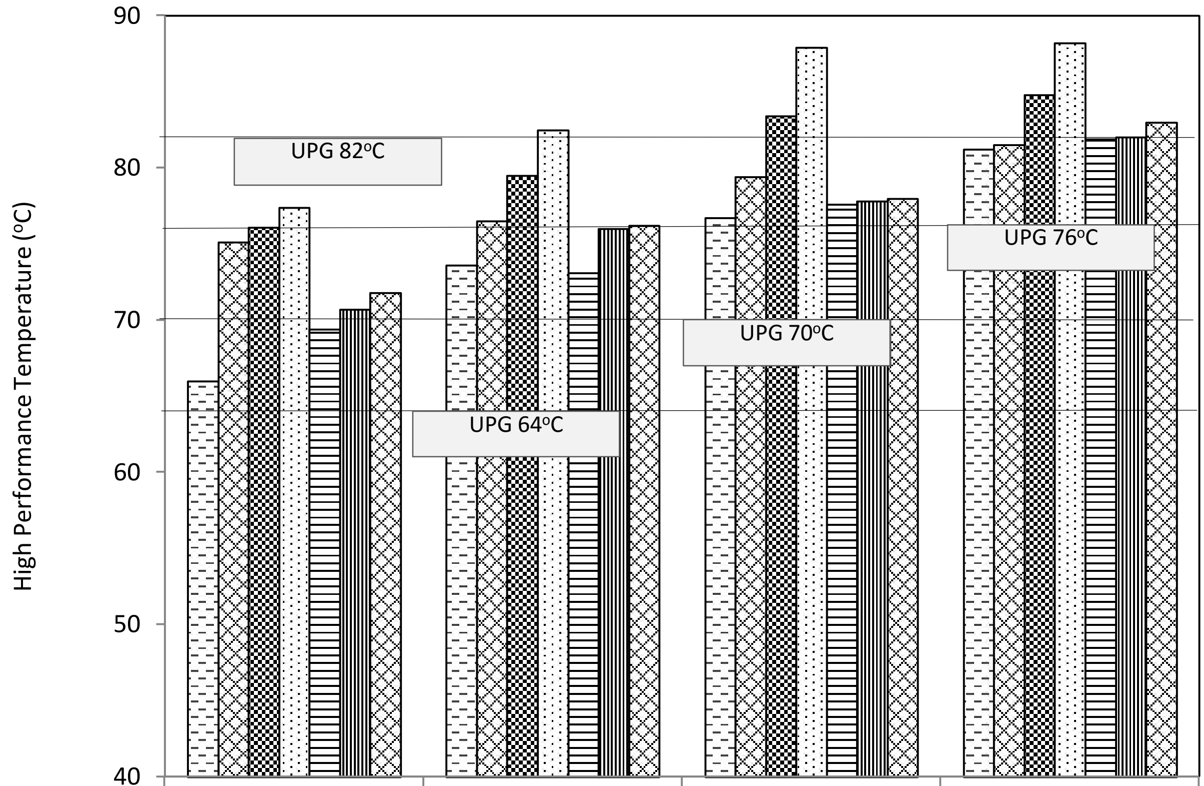
Figure 4.17: G*/Sinδ Values of 4% LDPE and 1% SBS Modified binder (RTFO Condition)

From the Figures 4.16 and 4.17, it was found that for fresh blend 79.6ºC is the actual grade temperature while for RTFO condition 79.4ºC is the actual grade temperature. So the lower of above two values is the critical one, which is 79.4ºC, has been selected as upper temperature grade for L4S1 modified asphalt. In similar approach UPG for all selected modified asphalt blends were calculated & presented in Table 4-4 and in Figures 4.18, 4.19 and 4.20.

Table 4-4: Upper Performance Grade (UPG) of the RPW modified Asphalt

RPW Type	RPW Content	Commercial Polymer (SBS)				Commercial Polymer (PB)			
		0%	1%	1.5%	2%	0%	1%	1.5%	2%
LDPE	0%	66.0	75.1	76.1	77.4	66.0	69.4	70.7	71.8
	2%	73.6	76.5	79.5	82.5	73.6	73.1	76.0	76.2
	4%	76.7	79.4	83.4	87.9	76.7	77.6	77.8	78.0
	6%	81.2	81.5	84.8	88.2	81.2	81.9	82.0	83.0
HDPE	0%	66.0	75.1	76.1	77.4	66.0	69.4	70.7	71.8
	2%	72.2	76.5	79.7	78.0	72.2	73.6	74.3	74.5
	4%	81.7	81.3	85.5	86.2	81.7	79.9	80.2	80.3
	6%	86.7	85.8	89.9	88.9	86.7	83.3	88.2	89.0
PP	0%	66.0	75.1	76.1	77.4	66.0	69.4	70.7	71.8
	2%	80.7	79.1	79.9	78.0	80.7	84.0	81.3	80.2
	4%	83.0	79.7	81.0	82.0	83.0	85.8	84.5	81.3
	6%	85.6	82.2	86.2	85.8	85.6	88.1	87.8	83.8

All asphalt blends modified with recycled LDPE with SBS and PB pass upper performance grade 70^{o}C, 7 blends pass UPG 82^{o}C 14 blends pass 76 ^{o}C and 5 blends passes 70 ^{o}C.

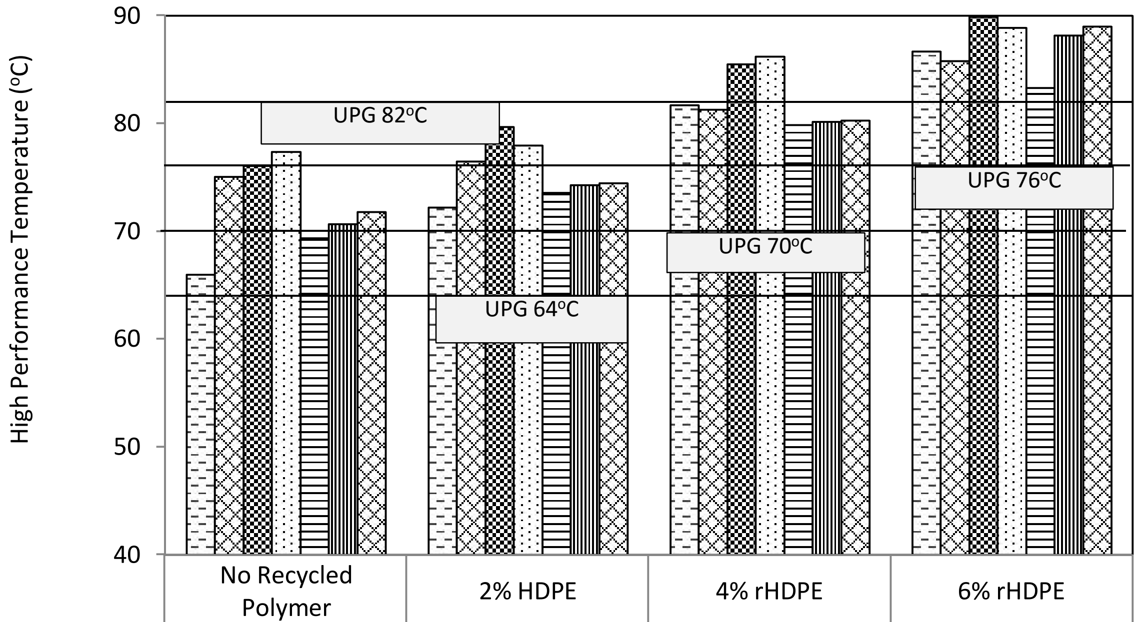


	No Recycled Polymer	2% rLDPE	4% rLDPE	6% rLDPE
No C. Poly	66	73.6	76.7	81.2
1% SBS	75.1	76.5	79.4	81.5
1.5% SBS	76.1	79.5	83.4	84.8
2% SBS	77.4	82.5	87.9	88.2
1% PB	69.4	73.1	77.6	81.9
1.5% PB	70.7	76	77.8	82
2% PB	71.8	76.2	78	83

Recycled Polymer Content

Figure 4.18: Upper Performance Grade of LDPE Modified Asphalt with SBS and PB

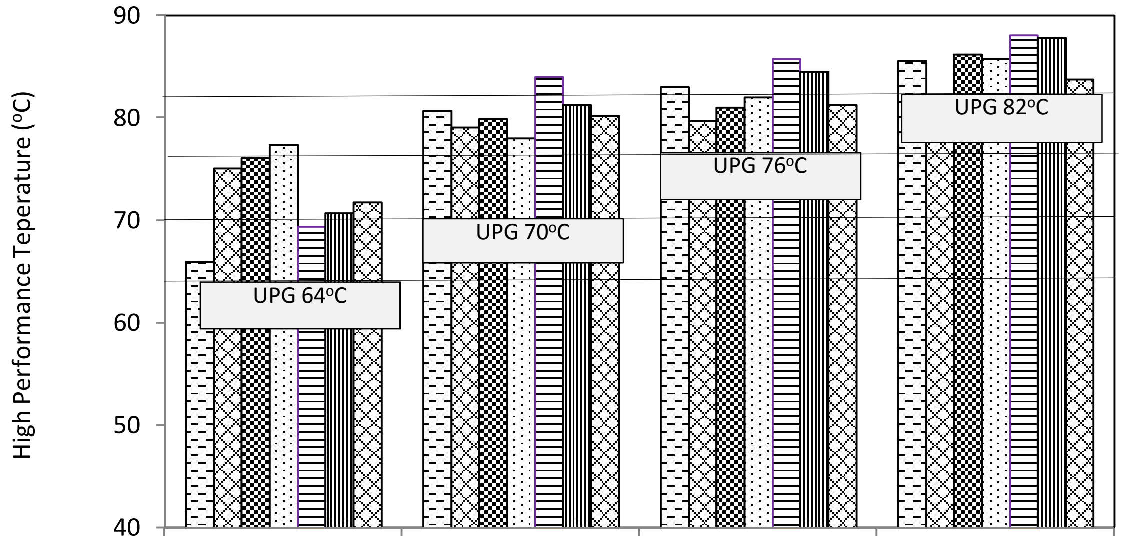
Improvement of upper performance grade of asphalt modified with recycled HDPE with SBS and PB has been depicted in Figure 4.19. Total 10 blends pass upper PG 82 ºC



	No Recycled Polymer	2% HDPE	4% rHDPE	6% rHDPE
No C. Poly	66	72.2	81.7	86.7
1% SBS	75.1	76.5	81.3	85.8
1.5% SBS	76.1	79.7	85.5	89.9
2% SBS	77.4	78	86.2	88.9
1% PB	69.4	73.6	79.9	83.3
1.5% PB	70.7	74.3	80.2	88.2
2% PB	71.8	74.5	80.3	89

Figure 4.19: Upper Performance Grade of HDPE Modified Asphalt with SBS and PB

8 blends pass 76 ºC and 7 blends pass 70 ºC. Figure 4.20 shows upper performance grade result of recycled PP and SBS, PB modified binder. Most of the blend pass 70ºC , 9 blends pass 82 ºC, 10 blends pass 76 ºC.



	No Recycled Polymer	2% rPP	4% rPP	6% rPP
No C. Poly	66	80.7	83	85.6
1% SBS	75.1	79.1	79.7	82.2
1.5% SBS	76.1	79.9	81	86.2
2% SBS	77.4	78	82	85.8
1% PB	69.4	84	85.8	88.1
1.5% PB	70.7	81.3	84.5	87.8
2% PB	71.8	80.2	81.3	83.8

Recycled Polymer Content

Figure 4.20: Upper Performance Grade of PP Modified Asphalt with SBS and PB

4.5.1 Effect of LDPE and SBS on UPG

Improvement of upper performance grades of asphalt modified by recycled LDPE and SBS is illustrated in Figure 4.21. General increase is observed for the blend of 0% LDPE line that start at 66^{o}C with 0% SBS and passes 76^{o}C at 1.5% SBS and ended at about 77^{o}C with 2% SBS. Adding 2% recycled polymer with commercial SBS produce a blend that increased UPG to 82^{o}C and 76ºC temperatures but further addition of 4% LDPE increases the passing temperature up to 82ºC.

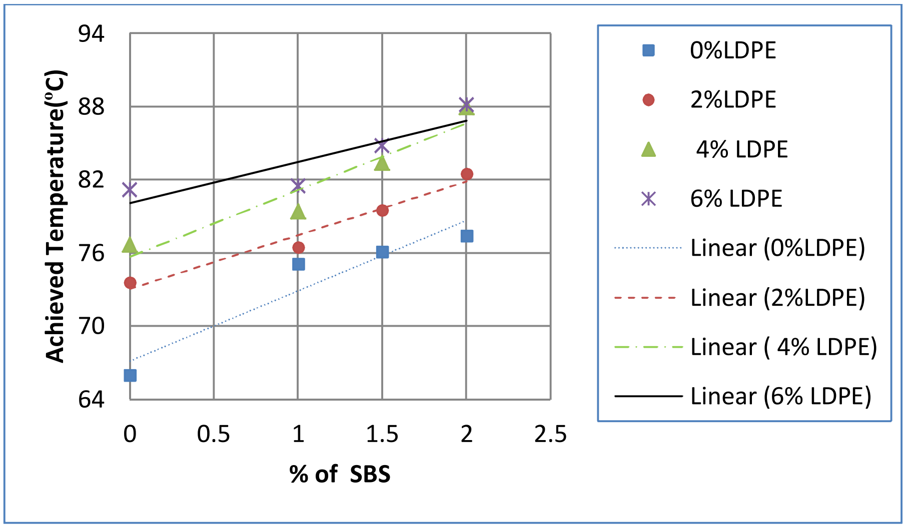


Figure 4.21: Effect of LDPE & SBS on UPG

This improvement with addition of LDPE can contribute to eliminate the uses of costly commercial modifier. Similarly 1% SBS with 6% LDPE will also give our targeted achieved temperature (82ºC).

4.5.2 Effect of LDPE and PB on UPG

Substantial changes is observed in performance grade (PG) when polybilt(PB) were used with recycled LDPE. This is depicted in Figure 4.22.

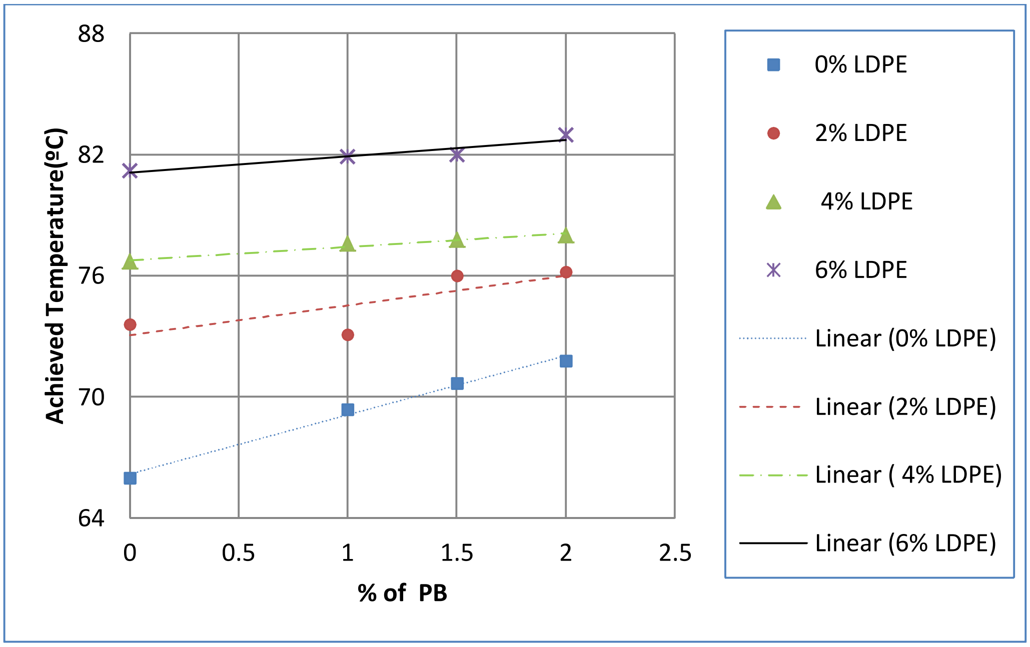


Figure 4.22: Effect of LDPE & PB on UPG

To attain 82ºC temperature 1% polybilt along with 6% recycled LDPE can be used and for 76ºC temperature one should use 2% LDPE with 2% polybilt.

4.5.3 Effect of HDPE and SBS on Upper Performance Grade

Recycled HDPE with SBS revealed substantial improvements in terms of high service temperature.

It is observed from Figure 4.23 that the addition of commercial elastomer (SBS) with recycled HDPE increases the upper performance grade of bitumen. Using above figure the Table 4-5 is developed to get the optimum content of recycled polymer with commercial polymer.

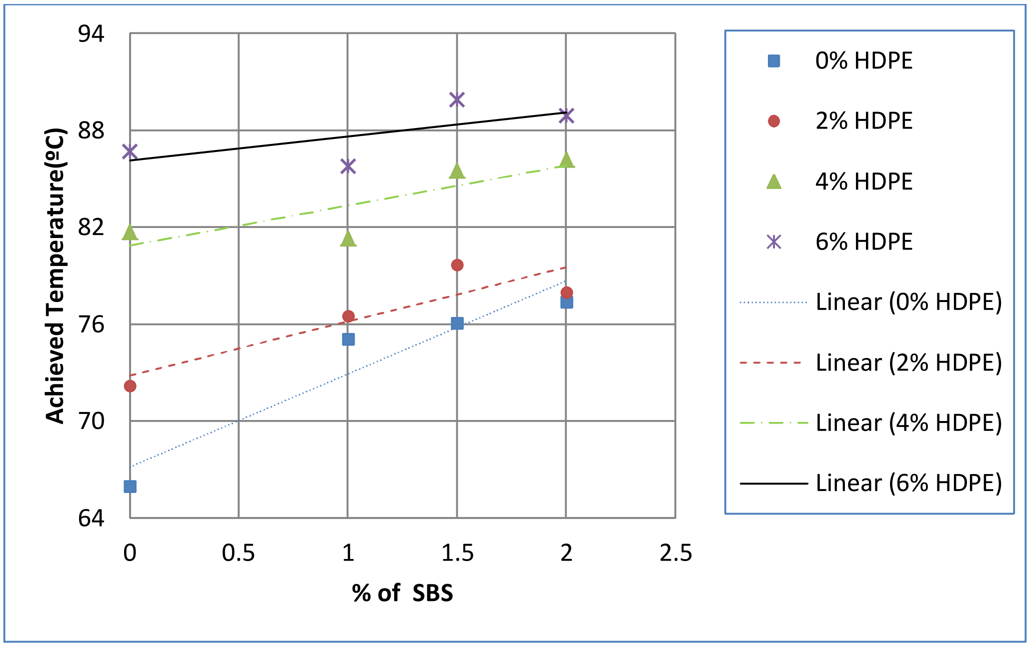


Figure 4.23: Effect of HDPE & SBS on UPG

From the UPG results following Table 4-5 and is developed that can be used to determine optimum polymer content to get targeted PG.

Table 4-5: Optimum Polymer (recycled & commercial) Content to attain UPG 82ºC & 76 ºC

Target PG	82ºC					
Blends	1	2	3	4	5	6
LDPE content	6%	4%	2%	6%	-	-
HDPE content	-	-	-	-	4%	4%
SBS content	1%	1.5%	-	1.1%	1.1%	-
PB Content	-	-	2%	-	-	-
Target PG	76ºC					
Blends	7	8	9	10	11	12
LDPE content	-	2%	2%	4%	-	-
HDPE content	-	-	-	-	2%	3.1%
PP content	1.5%	-	-	-	-	-
SBS content	-	0.6%	-	-	1%	-
PB Content	-	-	1.5%	-	-	-

Improvement of upper performance grade can be compared with previous study of Saudi Arabian asphalt modification by commercial polymer. For commercial polymer use in asphalt modification, the properties and grade of polymer is clearly known. For recycled polymer utilization locally available plastic waste of any grade or any properties is used. So the possibility of getting slightly different findings in terms of UPG or rutting resistance properties is usual. More over some plastic container or bottle of HDPE, LDPE or PP having recycle notation mark (2, 4, and 5) but in reality different additives ccould be mixed with them.

Based on the research of Isam Anaker Mohmmod (2002), 3% of Linear Low Density Polyethylene of Grade 1182 and 3% of High Density Polyethylene of grade M200056 with Rastanura asphalt separately improve UPG 76^{o}C .

On the other hand current study findings suggest that 4% recycled LDPE improve the UPG of Rastanura asphalt to 76^{o}C whereas 3% recycled HDPE gives the same performance. So recycled HDPE of this study performance in terms of UPG is similar to that of commercial HDPE of grade M200056 but recycled LDPE performance is slightly different than the commercial LLDPE of grade 1182.

4.6 Cost Analysis

This section performs a cost analysis to show the relative comparison in terms of cost of material used in conventional modification methods with respect to material cost of proposed modification methods in order to attain upper performance temperatures 76^{o}C & 82^{o}C.

4.6.1 Cost Analysis Background

The price of polymer depends upon many factors such as basic prices of oils, ethane, capacity utilization and stability between supply and demand. Thus there is always fluctuation of commercial polymer price all over the year. This comparative study used average price during the study period. Exon Mobil Company was contacted to get the price of commercial polybilt and SBS. The price of SBS were also collected from other source (ICIS Chemicals) and found almost similar. For the price of recycled HDPE, LDPE and PP, some small scale local recycling stores were contacted and interviewed to get the price per tons of each type. Based on the prices, average price is taken as the final one. Table 4-6 shows those prices.

Table 4-6: Market price of recycled and commercial polymer

Polymer	Code	Price per MT (SAR)
Recycled Low Density Polyethylene	rLDPE	3000.00
Recycled High Density Polyethylene	rHDPE	3000.00
Commercial Polybilt	cPB	7897.50
Commercial Styrene-Butadyne- Styrene	cSBS	9750.00

Findings from previous study of PMB in Saudi Arabian region are studied and the following 4 conventional modifications (Table 4-7) are selected to compare with modification of current research (Table 4-8).

Table 4-7: Conventional Modification of Asphalt

Targeted PG	Blends	Code	Commercial Polymer	Amount of Polymer	Reference
82^{o}C	Conventional Blend-1	CB-1	SBS	5.1%	K. J. Al-Adham (2014)
82^{o}C	Conventional Blend-3	CB-3	Polybilt	6.9%	K. J. Al-Adham (2014)
76^{o}C	Blend-2	CB-2	SBS	3.34%	K. J. Al-Adham (2014)
76^{o}C	Conventional Blend-4	CB-4	Polybilt	4.7%	K. J. Al-Adham (2014)

Findings of current study include a total of 12 promising blends which are summarized in Table 4-8, from which 6 blends yield upper performance grade (PG) 82^{o}C and other 6 yield UPG 76 ^{o}C.

Table 4-8: List of Promising Modification Suggested in this Research

Targeted PG	Blends	Code	Polymer Content
82°C	Blend-1	B-1	6% rLDPE +1% cSBS
	Blend -2	B-2	4% rLDPE +1.5% cSBS
	Blend -3	B-3	2% rLDPE +2% cPB
	Blend -4	B-4	6% rLDPE +1.1% cPB
	Blend -5	B-5	4% rHDPE +1.1% cSBS
	Blend -6	B-6	4.4% rHDPE +0% cSBS
76°C	Blend -7	B-7	1.5% rPP +0% cSBS
	Blend -8	B-8	2% rLDPE +0.6% cSBS
	Blend -9	B-9	2% rLDPE +1.5% cPB
	Blend -10	B-10	4% rLDPE +0% cPB
	Blend -11	B-11	2% rHDPE +1% cSBS
	Blend -12	B-12	3.1% rHDPE +0% cPB

Amount of commercial modifier to increase the upper performance grade of 1 metric tons of virgin asphalt to 82°C and 76°C were calculated. Similarly amount of recycled plastics and commercial polymers were also calculated for all alternative blends to attain upper performance grade 82°C and 76°C. Finally the material cost associated with each blend is compared to corresponding conventional blends. Polymer cost of alternative blends of current study are expressed as percentage of corresponding conventional commercial polymer.

4.6.2 Cost Analysis Result

In this segment findings are graphically presented with four following groups.

(a) Comparison with conventional SBS modified asphalt with target UPG 82°C

(b) Comparison with conventional PB modified asphalt with target UPG 82°C

(c) Comparison with conventional SBS modified asphalt with target UPG 76°C

(d) Comparison with conventional PB modified asphalt with target UPG 76°C

Material cost of 6 alternative blends (from B-1 to B-6) of current study is expressed as percentage of cost of conventional SBS modification (CB-1) to attain the upper performance grade 82°C are presented in Figure 4.24.

It is obvious from Figure 4.24 that to achieve targeted upper PG 82°C one can use any one of six alternative blends. For example, Blend-6, that is using only 4.4% HDPE at a material cost of almost 30 % of conventional blend (uses of SBS). So 70 % of modifier's cost can be saved.

Figure 4.25 shows material cost of 6 alternative blends (from B-1 to B-6) of current study as percentage of cost of conventional polybilt modification (CB-3) to attain the upper performance grade 82°C. In this case at a cost of 25% to 53% of conventional polybilt modifier cost, one can achieve UPG 82°C.

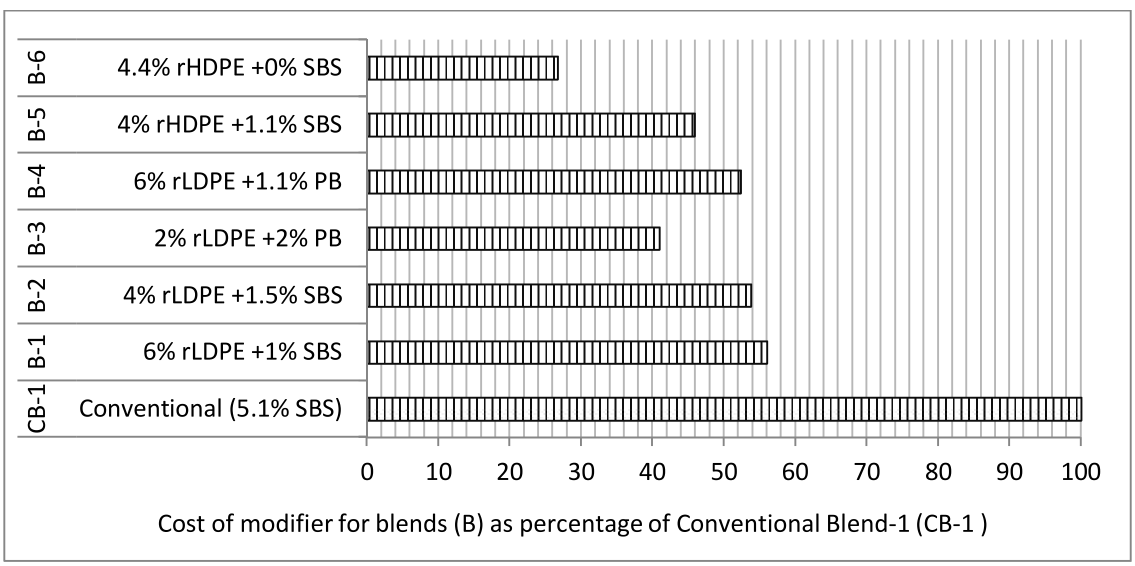


Figure 4.24: Cost of modifier for blends (B) as percentage of conventional commercial SBS for UPG 82

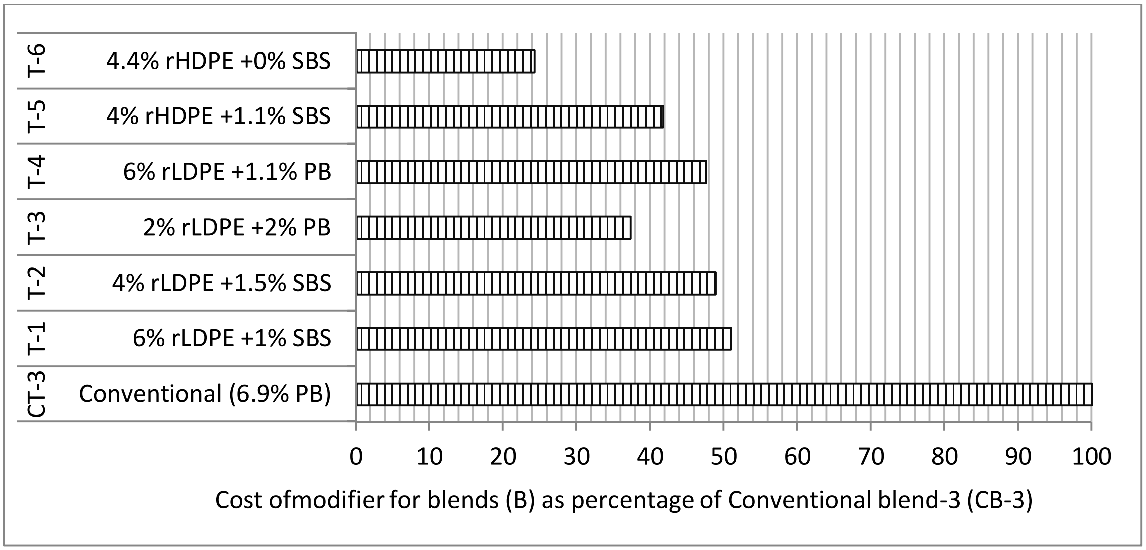


Figure 4.25: Cost of modifier for blends (B) as percentage of conventional commercial polybilt for UPG 82

To improve upper performance grade to 76°C this study suggests 6 alternative modifier solutions (B-7 to B-12). Their cost is compared with conventional SBS modifier (CB-2) and presented in Figure 4.26.

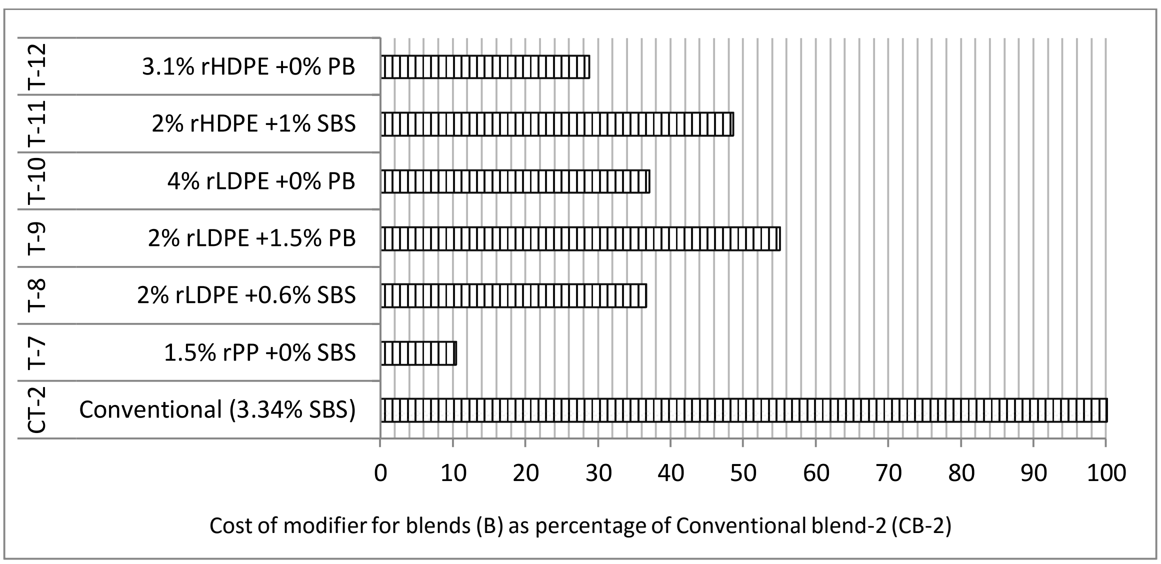


Figure 4.26: Cost of modifier for blends (B) as percentage of conventional commercial SBS modifier for UPG 76

For instances of the comparison with CB-2, blend -7 is found as the most cost effective alternative with a saving of almost 90% cost, blend-9 is found comparatively least cost effective solution with a saving of almost 40% cost of material.

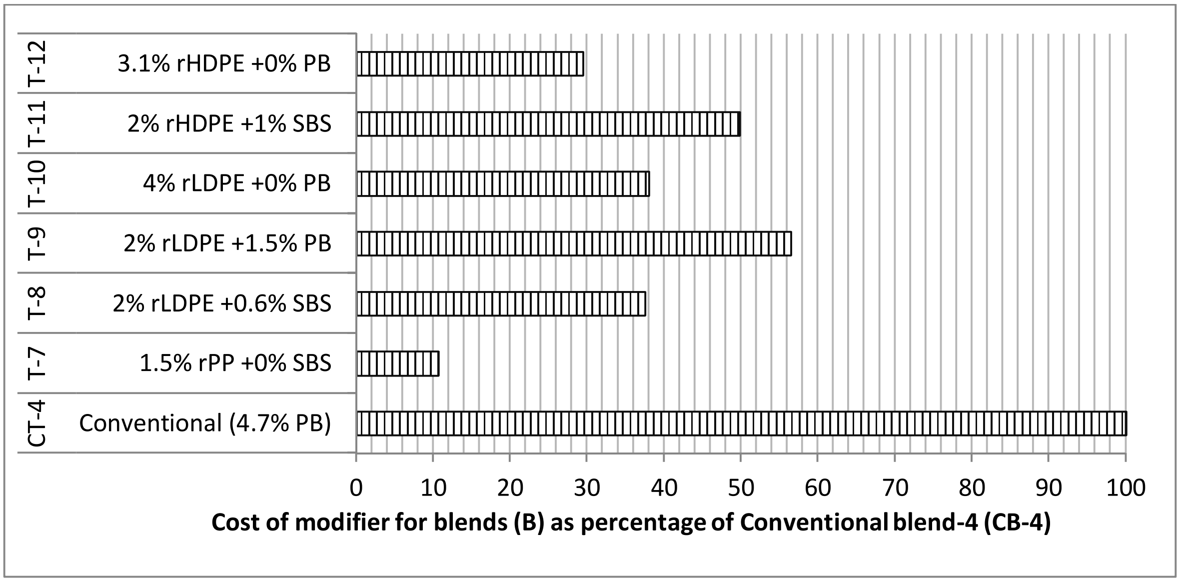


Figure 4.27: Cost of modifier for blends (B) as percentage of commercial polybilt modifier for UPG 76

To achieve upper performance grade 76^{o}C and to compare with CB-4(modification with polybilt), blend-7 to blend-12 shows substantial savings of material cost and that is presented in Figure 4.27.

In this case blend-7, cost of modifier is found to be almost 88% less than that of CB-4, some other alternatives are also found to be cost minimizing which ranges from 45% to 70%.

Cost analysis conducted here was concentrated only on the cost of modifier by setting aside the environmental concern. Benefit to eco system and saving waste management cost can be accounted to take decision to choose any alternative solution.

4.7 Statistical Analysis

Analysis of Variance (ANOVA) is a hypothesis testing procedure that tests whether two or more means are significantly different from each other. This ANOVA with a full factorial design was performed to investigate the significance of main effect and interaction effects in the experiment. The two main effects were commercial polymer content and recycled polymer content. A software package “R” of version i386 3.2.2 was used.

4.7.1 Assumption and Hypothesis

A full factorial design with two different factors each with four different levels is chosen to test the effect of recycled and commercial polymers on UPG. Following was the particulars of this statistical analysis:

Factor A: Commercial Polymer Content, **Levels**: 0%, 1%, 1.5% and 2%

Factor B: Recycled Polymer Content, **Levels** : 0%, 2%, 4% and 4%

Response Variables: Upper performance grade of modified binder

1st Null Hypothesis (H_{o1}) - First Main Effect:

There is no significant difference on the improvement of the upper performance grade by commercial polymer content

2nd Null Hypothesis (H_{o2}) - Second Main Effect:

There is no significant difference on the improvement of the upper performance grade by recycled polymer content

3rd Null Hypothesis (H_{o3}) – Interaction effect:

There is no significant interaction effect between commercial polymer content and recycled polymer content on the improvement of upper performance grade.

Alternate Hypothesis: Null hypothesis are not true

Significance Level (α):

A threshold value for significance level usually chosen by researchers is either 10%, 5% or 1% based on nature of experiment and sample size but usually 5% (95% Confidence level) is widely used by the scientific community. This study assumed 5% to use as the threshold value of significance level.

4.7.2 ANOVA Analysis Result

ANOVA results for recycled LDPE, HDPE and PP with SBS are illustrated in the Tables 4-9, 4-10 and 4-11. P-values for some factors are less than or equal to α (significance level) so null hypothesis are rejected for those factor and hence decided to have significant effect on upper performance grade. In contrast the factors having P-values larger than α are decided to have insignificant effect (do not reject the null hypothesis) on UPG.

Table 4-9:ANOVA result of HDPE and SBS blends for UPG

SN	Factor	P value	Status	Decision	Effect
1	rHDPE	0.00	P value < 0.05	Reject H_{02}	Significant
2	cSBS	0.00	P value < 0.05	Reject H_{01}	Significant
3	Interaction	0.08	P value > 0.05	Do not Reject H_{03}	Insignificant

It can be concluded form the ANOVA results that for HDPE and SBS blends, the two main effects has significant contribution to improve upper performance grade. On the other hand there is no significant interaction effect to improve UPG based on 95% confidence level.

Table 4-10: ANOVA result of LDPE and SBS blends for UPG

SN	Factor	P value	Status	Decision	Effect
1	rLDPE	0.00	P value < 0.05	Reject H_{02}	Significant
2	cSBS	0.00	P value < 0.05	Reject H_{01}	Significant
3	Interaction	0.10	P value > 0.05	Do not Reject H_{03}	Insignificant

LDPE and SBS interaction were also found to be insignificant however the two main effects are significant.

Table 4-11: ANOVA result of PP and SBS blends for UPG

SN	Factor	P value	Status	Decision	Effect
1	rPP	0.00	P value < 0.05	Reject H_{02}	Significant
2	cSBS	0.201	P value > 0.05	Do not Reject H_{01}	Insignificant
3	Interaction	0.123	P value > 0.05	Do not Reject H_{03}	Insignificant

Polypropylene with SBS shows poor performance in ANOVA analysis, to improve UPG, only the main effect (rPP) is found to be significant. The interaction effect and the SBS effect are insignificant.

Results for ANOVA analysis of blends with recycled LDPE, HDPE and PP with PB are illustrated in Tables 4-12, 4-13 and 4-14

Table 4-12: ANOVA Result of HDPE and PB blends for UPG

SN	Factor	P value	Status	Decision	Effect
1	rHDPE	0.00	P value < 0.05	Reject H_{02}	Significant
2	cPB	0.01	P value < 0.05	Reject H_{01}	Significant
3	Interaction	0.34	P value > 0.05	Do not Reject H_{03}	Insignificant

For the blends of recycled HDPE and commercial PB, two main effects and the interaction effect are significant. All the main effects and interaction effects are also significant in LDPE+PB blend for the improvement of UPG.

Table 4-13:ANOVA Result of LDPE and PB blends for UPG

SN	Factor	P value	Status	Decision	Effect
1	rLDPE	0.00	P value < 0.05	Reject H_{02}	Significant
2	cPB	0.00	P value < 0.05	Reject H_{01}	Significant
3	Interaction	0.02	P value <0.05	Reject H_{03}	Significant

The main effect of recycled PP is significant while the effect of commercial PB and the interaction effect of rPP and cPB are insignificant to improve the upper performance grade. This blend is not appropriate be used in asphalt.

Table 4-14:ANOVA Result of PP and PB blends for UPG

SN	Factor	P value	Status	Decision	Effect
1	rPP	0.00	P value < 0.05	Reject H_{02}	Significant
2	cPB	0.94	P value > 0.05	Do not Reject H_{01}	Insignificant
3	Interaction	0.303	P value >0.05	Do not Reject H_{03}	Insignificant

Within these six blends of recycled and commercial polymer modified binders, total 10 main effects out of 12 were found significant for the improvement of UPG. On the other hand one out of 6 interaction effects were found to be significant.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

Ever growing traffic demand and extreme temperature has necessitated the good quality pavement and hence good performing bituminous binder is becoming essential. Although asphalt modification by polymer has been studied for decades, still today there are some challenges. Among the challenges one of the major challenges is higher cost of commercial modifier conventionally used. This study reveals amazing cost effective solutions to those problems that improves locally produced asphalt's performance grade from 64^{o}C to an extreme of 82^{o}C and reduces problems related to non-disposable solid waste and its management.

One of the key purposes of this research was to be less dependent on costly, demanding commercial polymer resources and focusing on more on utilization of recycled polymer with a pursuit to rescue of opportunities that are lost every day to landfills. Among the twelve potential blends, it has been found that cost of alternate blend ranges from only 10% to 42 % of cost of conventional polymer popularly used. Low cost modification of this research will definitely attract the local agency and government bodies to extend the temperature susceptible range of locally produced asphalt and at the same time reducing unfavorable and non-ecofriendly plastic waste.

Environmental benefit is non-measurable but it has abundant value to provide us a good living world for tomorrow in fact eco-friendly solution is necessary for sustainable development. Agency or any government bodies can come forward to utilize those wasted opportunities from waste material to boost the business and to protect the environment. Following are the specific summery of some potential blends:

A. Low Density Polyethylene with SBS blend:

a. 4% LDPE with 1.5% SBS improve the Upper Performance Grade to 82^{o}C which saves 51% cost of modifier than conventional SBS modifier.

b. 2% LDPE with 0.6% SBS improve the Upper Performance Grade to 76^{o}C which saves 62% cost of modifier than conventional SBS modifier.

B. High Density Polyethylene with SBS blend:

a. 4% HDPE with 1.1% SBS improve the UPG to 82^{o}C which saves 54% cost of modifier than conventional modifier.

b. 2% HDPE with 1% SBS improve the UPG to 76^{o}C which saves 50% cost of modifier than conventional SBS modifier.

c. ANOVA prove HDPE-SBS interaction is significant on 90% confidence level

C. Polypropylene with SBS blend:

a. PB-SBS blend, SBS, PP & SBS interaction effects were found to be insignificant to improve UPG

b. 1.5% PP alone can improve the UPG to 76^{o}C which saves 90% cost of modifier than conventional modifier

D. High Density Polyethylene with PB blend:

a. 3.1 % HDPE alone improves the UPG to 76^{o}C which saves 71% cost of modifier than conventional SBS modifier.

b. ANOVA shows that the interaction effect of HDPE-PB is insignificant to improve UPG

E. Low Density Polyethylene with PB blend:

a. 6% rHDPE with 1.1% PB improve the UPG to 82^{o}C which saves 48% cost of modifier than conventional SBS modifier.

b. 2% rLDPE with 2% PB improves the UPG to 82^{o}C which saves 59% cost of modifier than conventional SBS modifier.

c. 2% rLDPE with 1.5% PB improve the UPG to 76^{o}C which saves 45% cost of modifier than conventional SBS modifier

d. ANOVA shows that the interaction effect of LDPE-PB is significant to improve UPG at 95% confidence interval

From the above six blends based on target upper performance grade, agency can choose any of the alternative blend solutions. For some of the blends to get same UPG, 2 or more alternative solutions are possible. For example blend-5 (4% rHDPE +1.1% cSBS) and blend-6 (4.4% rHDPE +0% cSBS) contribute the same performance grade (UPG 82) blend- 5 cost of 41.71% of conventional SBS modifier. On the other hand blend-6 with only at 55.03%. In blend-6 the amount of commercial SBS is reduced. So blend 6 is more eco-friendly than blend 5. In some extent, decision maker can choose blends with lower content of commercial polymer to save money and thus contribute to the environment for a better world.

Overall findings suggest that HDPE & SBS, LDPE & SBS LDPE & PB and HDPE & PB blends are most potential and laboratory test result proved that recycled plastic waste with slight addition of commercial polymer yields significant improvement on rutting resistance properties, temperature susceptible range of bitumen.

Recommendation for further study:

1. Potential blends that are found in this study can be used to explore further performance in terms of moisture susceptibility, fatigue life, elastic recovery and storage stability.
2. Findings of this study are based on laboratory experiment. It is recommended to explore the modification using waste plastic by constructing road section to monitor the actual performance.
3. Segregated recycled plastic wastes were used in this study which required extra time and energy for the sorting and identification of the polymer type. It is recommended to conduct further studies in asphalt modification using mixed plastic waste, which are directly collected from the source and without any sorting.

References

Abdul Wahhab, A., et al. (1997). "Development of performance-based bitumen specifications for the Gulf countries." Construction and Building Materials, 11 (1) : 15-22.

Al-Busaltan, S., Al Nageim, H., et al. (2012). "Green Bituminous Asphalt relevant for highway and airfield pavement". Construction and Building Materials 31 (2012) 243–250.

Al-Maaded, M., Madi, N. K., Kahraman, R., Hodzic, a., & Ozerkan, N. G. (2012). An Overview of Solid Waste Management and Plastic Recycling in Qatar. *Journal of Polymers and the Environment*, *20*(1), 186–194. http://doi.org/10.1007/s10924-011-0332-2.

Araujo, M. F. A., Lins, V. F. C., et al. (2013). "Weathering aging of modified asphalt binders". Fuel Processing Technology 115 (2013) 19-25.

Ameri, M., Mansourian, A., et al. (2013). "Laboratory evaluation of ethylene vinyl acetate modified bitumens and mixtures based upon performance related parameters". Construction and Building Materials 40 (2013) 438–447.

Ameri, M., Mansourian, A., et al. (2012). "Investigating effects of ethylene vinyl acetate and gilsonite modifiers upon performance of base bitumen using Superpave tests methodology". Construction and Building Materials 36 (2012) 1001-1007.

Ameri, M., Mansourian, A., et al. (2011). "Technical study on the Iranian Gilsonite as an additive for modification of asphalt binders used in pavement construction". Construction and Building Materials 25 (2011) 1379–1387.

Aflaki, S., Tabatabaee, N. (2009)."Proposals for modification of Iranian bitumen to meet the climatic requirements of Iran". Construction and Building Materials 23 (2009) 2141–2150.

Al-Hadidy, A., I., Tan, Y., (2009)."Mechanistic analysis of ST and SBS-modified flexible pavements". Construction and Building Materials 23 (2009) 2941-2950.

AI-Dubabe, B. I. A., Wahhab, H. I. A., et al. (1998). "POLYMER MODIFICATION OF ARAB ASPHALT". Journal of Materials in Civil Engineering, Vol.10, No.3, August,1998.

Alatas, T., Yilmaz, M., (2013)." Effects of different polymers on mechanical properties of bituminous bindersand hot mixtures". Construction and Building Materials 42 (2013) 161–167.

Alatas, T., Yılmaz, M., et al. (2012). “Comparison of permanent deformation and fatigue resistance of hot mix asphalts prepared with the same performance grade binders”. Construction and Building Materials 30 (2012) 66-72.

BaghaeeMoghaddam, T., M. R. Karim, et al. (2012). "Dynamic properties of stone mastic asphalt mixtures containing waste plastic bottles." Construction and Building Materials 34(0): 236-242.

Bowering, R. H., (1984).“Modified bitumens”. In: Proceedings of the Australian asphalt pavement association conference 84, 1984 Members Conference; 1984 August 27–28, Hobart, Tasmania. Kew, Victoria: Australian Asphalt Pavement Association; 1984.

Bueno, M., Hugener, M., et al. (2014). “Low temperature characterization of bituminous binders with a new cyclic shear cooling (CSC) failure test”. Construction and Building Materials 58 (2014) 16–24.

Brule B., Brion Y., and Tanguy A., (1988), “Paving Asphalt Polymer Blends: Relationships between Composition, Structure and Properties”, Proc., AAPT, 57: 41-64.

Casey, D., C. McNally, et al. (2008). "Development of a recycled polymer modified binder for use in stone mastic asphalt." Resources. Conservation and Recycling 52(10): 1167-1174.

Chaffin, C. W., O’Connor, D. L., et al. (1978). “Evaluation of the use of certain elastomers in asphalt”. Report No.: FHWA-TX-78180-1F Final Rpt. Washington, D.C.: Federal Highway Administration, July 1978.

Darabi, M. K., Al-Rub, R. K. A., et al. (2013). “Constitutive modelling of fatigue damage response of asphalt concrete materials with consideration of micro-damage healing”. International Journal of Solids and Structures 50 (2013) 2901–2913.

Delbono, H. L., and Giudice, C. A., (2014). “Adherence in a pavement rehabilitated with a polymeric grid used as interlayer”. Construction and Building Materials 54 (2014) 454–459.

Denning, J. H., Carswell, J., (1983). “Assessment of ‘Novophalt’ as a binder for rolled asphalt wearing course”. Report No.: TRRL Laboratory, Report 1101. Crowthorne, England: Transport and Road Research Laboratory; 1983.

Derraik, J. G. B. 2002 The pollution of the marine environment by plastic debris: a review.Mar. Pollut. Bull.44, 842 – 852. (doi:10.1016/S0025-326X(02)00220-5).

Dong, F., Zhao, W., et al. (2014). “Influence of SBS and asphalt on SBS dispersion and the performance of modified asphalt”. Construction and Building Materials 62 (2014) 1-7.

El Ashry, E. S. H., Awad, L., et al. (2008). “Modification of Asphalt Properties”. Progress in Rubber, Plastics and Recycling Technology, Vol. 24, No. 4, 2008; ProQuest pg. 273.

El-Wahab, H. A., Saleh, A. M. M., et al. (2013). “Preparation and evaluation of a new anti-corrosive coating based on asphalt cement blended with polyester amide resin for steel protection”. Progress in Organic Coatings 76 (2013) 1363–1368.

Fang, C., Liu, P., et al. (2014). “Preparation process to affect stability in waste polyethylene-modified bitumen”. Construction and Building Materials 54 (2014) 320-325.

Fang, C., Li, T., et al. (2008).“Modification of Asphalt by Packaging Waste-Polyethylene”. Polymer Composites; Vol. 29, No. 5, 2008; ProQuest pg. 500.

Fang, C., Wu, C., et al. (2014). “Pavement Properties of Asphalt Modified With Packaging-Waste Polyethylene”. JOURNAL OF VINYL & ADDITIVE TECHNOLOGY-(2014) 31-35.

Fang, C., Wu, C., et al. (2013). "Aging properties and mechanism of the modified asphalt by packaging waste polyethylene and waste rubber powder." Polymers for Advanced Technologies 24(1): 51-55.

Fang, C., Yu, R., et al. (2013). “Preparation and characterization of an asphalt-modifying agent with waste packaging polyethylene and organic montmorillonite”.Polymer Testing 32 (2013) 953–960.

Fang, C., R. Yu, et al. (2012). "Combined modification of asphalt with polyethylene packaging waste and organophilic montmorillonite." Polymer Testing 31(2): 276-281.

Fang, C., Zhang, Y., et al. (2013). “Preparation, Characterization and Hot Storage Stability of Asphalt Modified by Waste Polyethylene Packaging”. J. Mater. Sci. Technol., 2013, 29(5), 434-438.

Fang, C., M. Zhang, et al. (2009). "UV-Aging Resistance of Packaging Waste PE Modified Asphalts." Polymer- Plastics Technology and Engineering 48(9): 945-949.

Fang, C., S. Zhou, et al. (2009). "Modification of waterproofing asphalt by PVC packaging waste." Journal of Vinyl and Additive Technology 15(4): 229-233.

García, A., Bueno, M., et al. (2013).“Induction healing of dense asphalt concrete”. Construction and Building Materials 49 (2013) 1–7.

Geng, J., Li, H., et al. (2014). “Changing Regularity of SBS in the Aging Process of Polymer Modified Asphalt Binder Based on GPC Analysis”. International Journal of Pavement Research and Technology 7(1):77-82.

Giuliani, F., Merusi, F., et al. (2009).“Effects of polymer modification on the fuel resistance of asphalt binders”. Fuel 88 (2009) 1539–1546.

Garcia-Morales, M., P. Partal, et al. (2003)."Linear Viscoelasticity of Recycled EVA-Modified Bitumens." Energy & Fuels 18(2): 357-364.

Gregory, M. R. 2009 Environmental implications of plastic debris in marine settings—entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. Phil. Trans. R. Soc. B364, 2013–2025. (doi:10.1098/rstb.2008.0265).

Gregory, M. R. 1978 Accumulation and distribution of virgin plastic granules on New Zealand beaches. N. Z. J. Mar. Freshwater Res.12, 339 – 414.

Gulati V. (2010). Indian state uses plastic waste for road construction. One World South Asia (article) :
http://southasia.oneworld.net/news/indian-state-uses-plastic-waste-for-road-construction

Hamzah, M. O., Kakar, M. R., et al. (2014).“Quantification of moisture sensitivity of warm mix asphalt using image analysis technique”. Journal of Cleaner Production 68 (2014) 200-208

Ho, S., R. Church, et al. (2006). "Study of recycled polyethylene materials as asphalt modifiers." Canadian Journal of Civil Engineering 33(8): 968-981.

Isacsson, U., Lu, X., (1995). “Testing and appraisal of polymer modified road bitumens – state of the art”. Mater Struct 1995;28(3): 139–59.

Isam Abaker, (2002). “Performance Modification of Saudi-Asphalt Binders Using SABIC Polymers. MS Dissertation Report.

Jasso, M., Bakos, D., et al. (2012). “Conventional asphalt modified by physical mixtures of linear SBS and montmorillonite”. Applied Clay Science 70 (2012) 37–44.

Johnson, R., (1987). “History and development of modified bitumen”. In: Proceedings of the 8th conference on roofing technology; 1987 April 16–17; Gaithersburg, Maryland. Rosemont, Illinois: National Roofing Contractors Association; 1987. p. 81–4.

Kaloush, K. E., (2014). “Asphalt rubber: Performance tests and pavement design issues”. Construction and Building Materials xxx (2014) xxx–xxx.

Kameau, G., Duron, M., (1976). “Influence of static and sequenced elastothermoplastic copolymers on the mechanical properties of bituminous mixtures”. Bulletin de Liaison des Laboratories des Ponts et Chaussées 1976;18:135–9 [In French].

Katami, T., Yasuhara, A., Okuda, T. & Shibamoto, T. 2002 Formation of PCDDs, PCDFs, and coplanar PCBs from polyvinyl chloride during combustion in an incinerator. Environ. Sci. Technol. 36, 1320 – 1324. (doi:10.1021/es0109904).

Kim, D. M., Busch, M., et al. (2004).“Molecular weight distribution modeling in low-density polyethylene polymerization; impact of scission mechanisms in the case of CSTR”. Chemical Engineering Science 59 (2004) 699–718.

Kim, S., Lee, S.J., et al. (2014). “The use of CRM-modified asphalt mixtures in Korea: Evaluation of high and ambient temperature performance”. Construction and Building Materials xxx (2014) xxx–xxx.

Kim, D. Y., Menches, C. L., et al. (2013). “Comparative Simulation Analysis of Pavement Technology for a Decision Support System in the U.S. Road Renewal Industry”. KSCE Journal of Civil Engineering (2014) 18(4):920-926.

Kök, B. V., Yılmaz, M., et al. (2014). “Evaluation of the conventional and rheological properties of SBS + Sasobit modified binder”. Construction and Building Materials 63 (2014) 174–179.

Kraus, G., (1982). “Modification of asphalt by block polymers of butadiene and styrene”. Rubber ChemTechnol 1982;55(5):1389–402.

K.J. Al-Adham (2014), Dissertation Report “Elastic Recovery Evaluation of Saudi Asphalt Modified with Commercial Polymers”

Laist, D. W. 1997 Impacts of marine debris: entanglement of marine life in marine debris including a comprehensive list of species with entanglement and ingestion records. In Marine debris: sources, impacts and solutions(eds J. M. Coe & B. D. Rogers), pp. 99 –141. Berlin, Germany: Springer.

Lesueur, D. (2009). “The colloidal structure of bitumen: Consequences on the rheology and on the mechanisms of bitumen modification”. Advances in Colloid and Interface Science 145 (2009) 42-82.

Luong, J., Bueno, M., et al. (2014). “Ultrathin porous pavement made with high viscosity asphalt rubber binder: A better acoustic absorption?”. Applied Acoustics 79 (2014) 117–123.

Li, P., Jiang, K., et al. (2012). “High-Temperature Stability of Asphalt Mixture with the Influence of Styrene Butadiene Styrene”.Procedia - Social and Behavioral Sciences 43 (2012) 842-848.

Li, Q., Ni, F., et al. (2014). “Evaluating the rutting resistance of asphalt mixtures using an advanced repeated load permanent deformation test under field conditions”. Construction and Building Materials 61 (2014) 241–251.

Leonenko, V. V., Safonov, G. A. (2001). “SOME ASPECTS OF MODIFICATION OF ASPHALTS WITH POLYMERIC MATERIALS” Chemistry and Technology of Fuels and Oils, Vol. 37, No. 5, 2001.

Muniandy, R., Akhir, N. A. B. C. M., et al. (2014). “Laboratory fatigue evaluation of modified and unmodified asphalt binders in Stone Mastic Asphalt mixtures using a newly developed crack meander technique”. International Journal of Fatigue 59 (2014) 1–8.

Modarres, A., Hamedi, H., (2014). “Effect of waste plastic bottles on the stiffness and fatigue properties of modified asphalt mixes”. Materials and Design 61 (2014) 8–15.

Moore, C. J. 2008 Synthetic polymers in the marine environment: a rapidly increasing, long-term threat.Environ. Res.108, 131 – 139. (doi:10.1016/j.envres. 2008.07.025).

Min, K. E., Jeong, H. M., (2013). “Characterization of air-blown asphalt/trans-polyoctenamer rubber blends”. Journal of Industrial and Engineering Chemistry 19 (2013) 645–649.

Murphy, M., M. O'Mahony, et al. (2000). "Bitumens modified with recycled polymers." Materials and Structures 33(7): 438-444.

Navarro, F. J., P. Partal, et al. (2009). "Bitumen modification with reactive and non-reactive (virgin and recycled) polymers: A comparative analysis." Journal of Industrial and Engineering Chemistry 15(4): 458-464.

Ouda, O. K. M., & Cekirge, H. M. (2013). Roadmap for Development of Waste-to Energy Facility in Saudi Arabia. *American Journal of Environmental Engineering*, *3*(6), 267–272. http://doi.org/10.5923/j.ajee.20130306.01.

Özen, H. (2011). “Rutting evaluation of hydrated lime and SBS modified asphalt mixtures for laboratory and field compacted samples”. Construction and Building Materials 25 (2011) 756-765.

Ouyang, C., Wang, S., et al. (2006). “Improving the aging resistance of styrene butadiene styrene tri-block copolymer modified asphalt by addition of antioxidants”. Polymer Degradation and Stability 91 (2006) 795-804.

Parvez, M. A., Al-Mehthel, M., et al. (2013).“Utilization of Sulphur and Crumb Rubber in Asphalt Modification”. J. APPL. POLYM. SCI.2014, DOI: 10.1002/APP.40046.

Polacco, G., Berlincioni, S., et al. (2005). “Asphalt modification with different polyethylene-based polymers”. European Polymer Journal 41 (2005) 2831–2844.

Presti, D. L., (2013). “Recycled Tyre Rubber Modified Bitumens for road asphalt mixtures: A literature review”. Construction and Building Materials 49 (2013) 863–881.

Peralta, J., Silva, H. M. R. D., et al. (2012). “Mutual changes in bitumen and rubber related to the production of asphalt rubber binders”. Construction and Building Materials 36 (2012) 557–565.

Polacco, G., Stastna, J., et al. (2006).“Relation between polymer architecture and nonlinear viscoelastic behaviour of modified asphalts”. Current Opinion in Colloid & Interface Science 11 (2006) 230–245.

Punith, V. and A. Veeraragavan (2011). "Behavior of Reclaimed Polyethylene Modified Asphalt Cement for Paving Purposes." Journal of Materials in Civil Engineering 23(6): 833-845.

Qin, Q., Farrar, M. J., et al. (2014). “Morphology, thermal analysis and rheology of Sasobit modified warm mix asphalt binders”. Fuel 115 (2014) 416–425.

Qin, Q., Schabron, J. F., et al. (2014). “Field aging effect on chemistry and rheology of asphalt binders and rheological predictions for field aging”. Fuel 121 (2014) 86–94.

Rahman, F., M. N. Siddiqui, et al. (2006)."Catalytic Processing of Waste Plastics With/Without Petroleum Resid— An Economic Evaluation. “Energy Sources. Part A: Recovery. Utilization, and Environmental Effects 28(15): 1353-1363.

Reese, R., Predoehl, N. H., (1989). “Evaluation of modified asphalt binders-Interim report”. Report No.: FHWA/CA/TL-89/15. Washington, D.C.: Federal Highway Administration; 1989 September.

Rostler, F. S., White, R. M., et al. (1972). “Modification of asphalt cements for improvement of wear resistance of pavement surfaces”. Report No.: FHWA-RD-72-24 Final Rpt. Washington, D.C.: Federal Highway Administration; 1972 March.

Scott, G. (2000). “Green”polymers. Polymer Degradation and Stability, 68, 1–7. Retrieved from.

Syroezhko, A. M., Begak, O. Y., et al. (2002). “Modification of Paving Asphalts with an Elastoplastic”. Russian Journal of Applied Chemistry, Vol. 75, No. 9, 2002, pp. 1525-1528.

Sureshkumar, M. S., Filippi, S., et al. (2010). “Internal structure and linear viscoelastic properties of EVA/asphalt nano composites”. European Polymer Journal 46 (2010) 621–633.

Sengoz, B., Isikyakar, G., (2008). “Evaluation of the properties and microstructure of SBS and EVA polymer modified bitumen”. Construction and Building Materials 22 (2008) 1897–1905.

Sangita, T. A. Khan, et al. (2011). "Effect of waste polymer modifier on the properties of bituminous concrete mixes." Construction and Building Materials 25(10): 3841-3848.

Singh, B., M. Gupta, et al. (2003). "Mastic of polymer-modified bitumen and poly(vinyl chloride) wastes." Journal of Applied Polymer Science 90(5): 1347-1356.

Seidel, J. C., Haddock, J. E., (2014). “Rheological characterization of asphalt binders modified with soybean fatty acids”. Construction and Building Materials 53 (2014) 324–332.

Singh, B., L. Kumar, et al. (2013). "Polymer-modified bitumen of recycled LDPE and maleated bitumen." Journal of Applied Polymer Science 127(1): 67-78.

Sulyman, M., Sienkiewicz, M., et al. (2014). “Asphalt Pavement Material Improvement: A Review”. International Journal of Environmental Science and Development, Vol. 5, No. 5, October 2014.

Thompson, R. C., Moore, C. J., vom Saal, F. S., & Swan, S. H. (2009). Plastics, the environment and human health: current consensus and future trends. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *364*(1526), 2153–66. http://doi.org/10.1098/rstb.2009.0053.

Toraldo, E., Brovelli, C., et al. (2013). “Laboratory investigation into the effects of working temperatures on wax-based warm mix asphalt”. Construction and Building Materials 44 (2013) 774–780.

Toraldo, E., Mariani, E., et al. (2014). “Effects of polymer additives on bituminous mixtures”. Construction and Building Materials 65 (2014) 38-42.

Thives, L. P., Pais, J. C., et al. (2013). "Assessment of the digestion time of asphalt rubber binder based on microscopy analysis". Construction and Building Materials 47 (2013) 431–440.

Teuten, E. L. et al. 2009 Transport and release of chemicals from plastics to the environment and to wild-life. Phil. Trans. R. Soc. B364, 2027 – 2045. (doi:10. 1098/rstb.2008.0284).

Underwood, B. S., and Kim, Y. R., (2014). "A four phase micro-mechanical model for asphalt mastic modulus". Mechanics of Materials 75 (2014) 13–33.

Utracki, L. A., (1995). "History of commercial polymer alloys and blends (from a perspective of the patent literature)".PolymEngSci 1995;35(1):2–17.

Vargas, M. A., Vargas, M. A., et al. (2013). "Asphalt/polyethylene blends: Rheological properties, microstructure and viscosity modeling". Construction and Building Materials 45 (2013) 243–250.

Vlachovicova, Z., Wekumbura, C., et al. (2006). "Creep characteristics of asphalt modified by radial styrene-butadiene-styrene copolymer". Construction and Building Materials 21 (2007) 567-577.

Widyatmoko, I., Elliott, R., (2008). "Characteristics of elastomeric and plastomeric binders in contact with natural asphalts". Construction and Building Materials 22 (2008) 239–249.

Wei, Z., Rebandt, R., Start, M., Gao, L. et al., "Approaches to Achieving High Reliability and Confidence Levels with Small Test Sample Sizes," SAE Int. J. Commer. Veh. 8(2):343-354, 2015, doi:10.4271/2015-01-2758.

Wei, J., Liu, Z. et al. (2013). "Rheological properties of amorphous poly alpha olefin (APAO) modified asphalt binders". Construction and Building Materials 48 (2013) 533–539.

Xiao, F., Amirkhanian, S., et al. (2014)."Rheological property investigations for polymer and polyphosphoric acid modified asphalt binders at high temperatures". Construction and Building Materials 64 (2014) 316–323.

Xiang, L., Cheng, J., et al. (2009). "Microstructure and performance of crumb rubber modified asphalt". Construction and Building Materials 23 (2009) 3586–3590.

Xue, Y., Wu, S., et al. (2014). "Effects of two biomass ashes on asphalt binder: Dynamic shear rheological characteristic analysis". Construction of Building and Materials (2014) 7-15.

Yilmaz, M., Çeloglu, M. E., (2013).“Effects of SBS and different natural asphalts on the properties of bituminous binders and mixtures”. Construction and Building Materials 44 (2013) 533-540.

Yildirim, Y., (2007). “Polymer modified asphalt binders”. Constr Build Mater 2007;21(1):66–72.

Yildirim, Y., D. Hazlett, et al. (2004). "Toner-modified asphalt demonstration projects." Resources. Conservation and Recycling 42(3): 295-308.

Yan, K., Zhang, H., et al. (2013). “Effect of polyphosphoric acid on physical properties, chemical composition and morphology of bitumen”. Construction and Building Materials 47 (2013) 92-98.

Yut, I., and Zofka, A., (2014). “Correlation between rheology and chemical composition of aged polymer-modified asphalts”. Construction and Building Materials 62 (2014) 109–117.

Zafar S. (2013). Solid Waste Management in Saudi Arabia. Eco Mena Articles (http://www.ecomena.org/solid- waste-management-in-saudi-arabia/)

Zenke, G., (1976). “On the use of polymer-modified bitumen in asphalt mixes”.Stationaere Mischwerk 1976;10(6):255–64 [In German].

Zhu, J., Birgisson, B., et al. (2014). “Polymer modification of bitumen: Advances and challenges”. European Polymer Journal 54 (2014) 18-38.

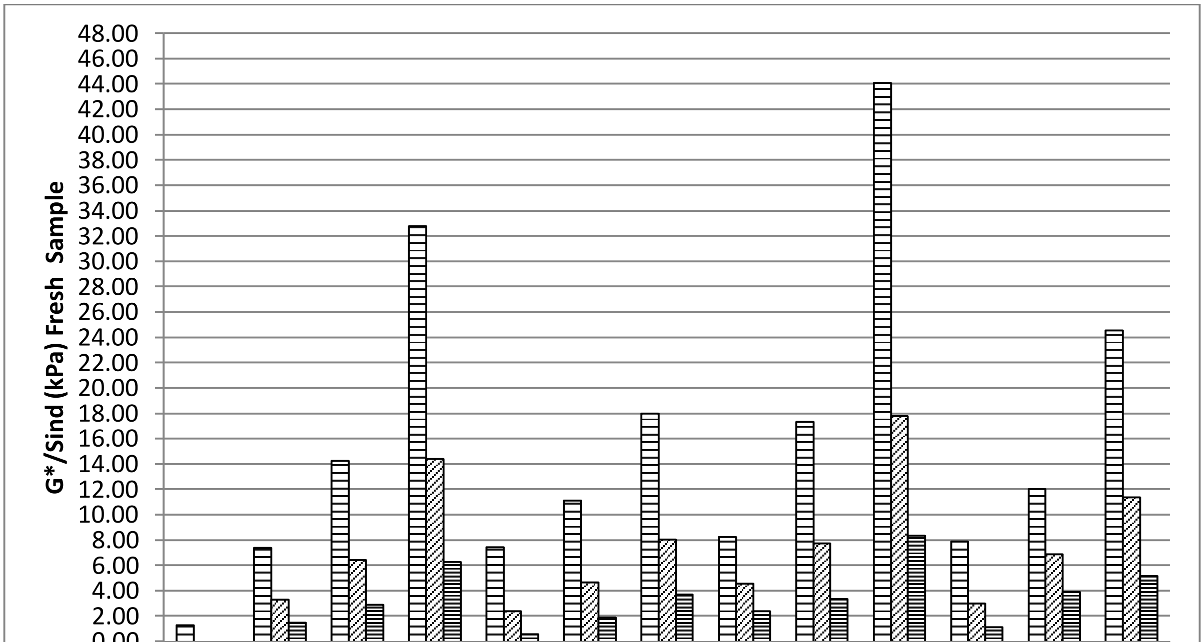
Zhi, S., Gun, W. W., et al. (2012). “Evaluation of fatigue crack behavior in asphalt concrete pavements with different polymer modifiers”. Construction and Building Materials 27 (2012) 117–125.

Zhang, F., Hu, C., (2013). “The research for SBS and SBR compound modified asphalts with polyphosphoric acid and sulfur”. Construction and Building Materials 43 (2013) 461-468.

APPENDICES

APPENDIX A

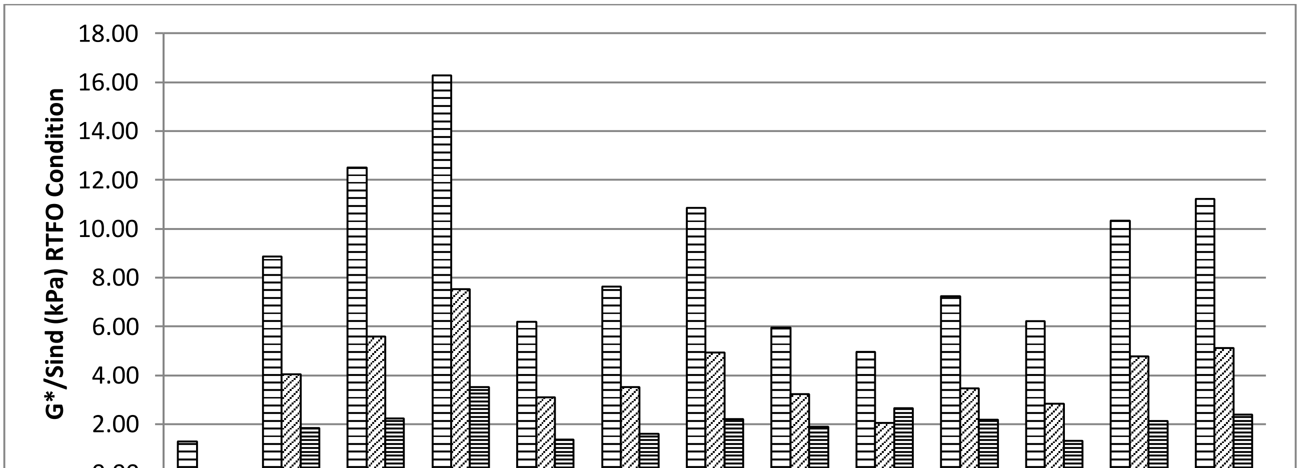
Rutting Resistance Parameter of Modified Binder at High temperature



	H0S0	H2S0	H4S0	H6S0	H2S1	H4S1	H6S1	H2S1.5	H4S1.5	H6S1.5	H2S2	H4S2	H6S2
70°C	1.306	7.41	14.27	32.84	7.47	11.18	18.03	8.27	17.38	44.15	7.95	12.06	24.60
76°C		3.35	6.48	14.42	2.42	4.70	8.11	4.58	7.80	17.83	3.05	6.90	11.43
82°C		1.52	2.94	6.33	0.59	1.90	3.72	2.45	3.37	8.39	1.15	3.97	5.20

Different Blend with Recycled HDPE and commercial SBS

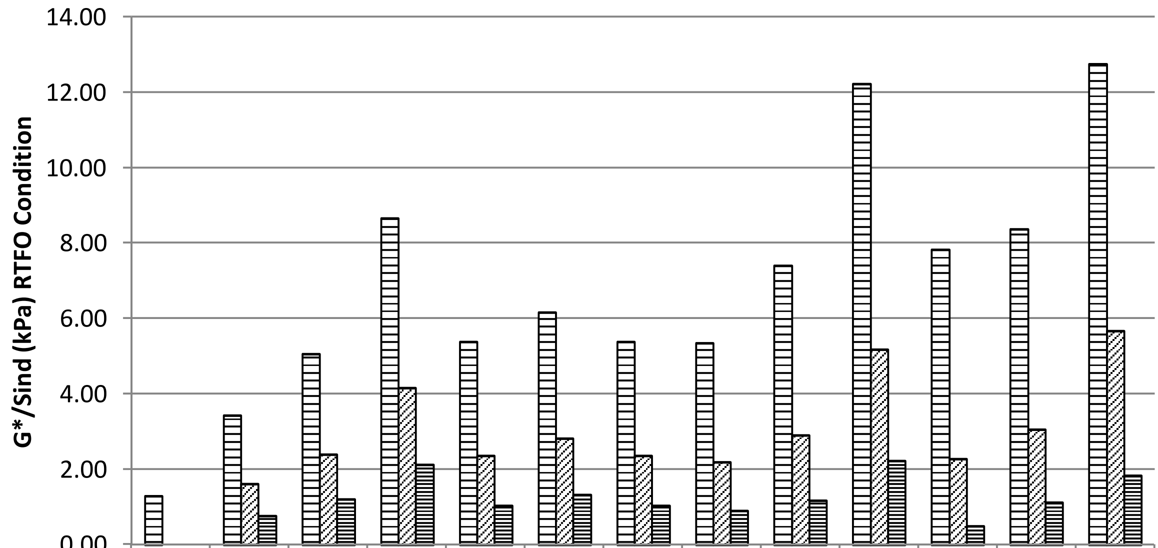
Figure A.1: Rutting resistance (G*/Sinδ) at high service temperature of rHDPE & SBS modified binder



	P0S0	P2S0	P4S0	P6S0	P2S1	P4S1	P6S1	P2S1.5	P4S1.5	P6S1.5	P2S2	P4S2	P6S2
70°C	1.31	8.89	12.53	16.30	6.21	7.65	10.87	5.98	4.99	7.25	6.24	10.36	11.25
76°C		4.08	5.61	7.55	3.12	3.53	4.96	3.26	2.08	3.48	2.85	4.79	5.15
82°C		1.86	2.25	3.55	1.40	1.62	2.24	1.92	2.67	2.21	1.35	2.15	2.40

Different Blend with Recycled PP and commercial SBS

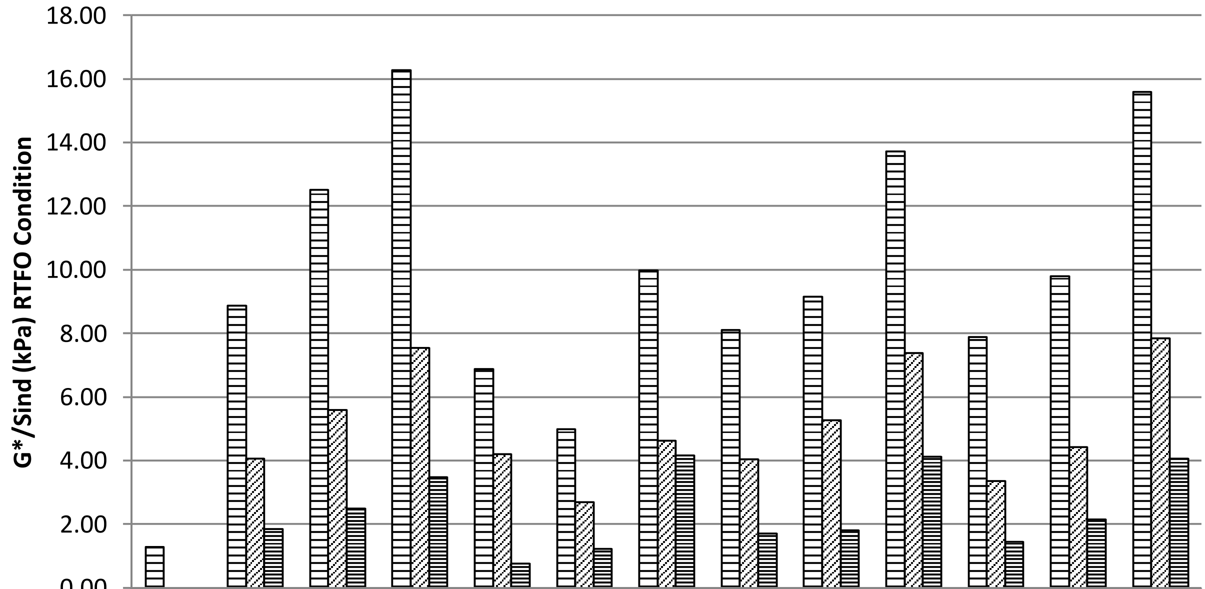
Figure A.2: Rutting resistance (G*/Sinδ) at high service temperature of rPP & SBS modified binder



	L0B0	L2B0	L4B0	L6B0	L2B1	L4B1	L6B1	L2B1.5	L4B1.5	L6B1.5	L2B2	L4B2	L6B2
70°C	1.306	3.435	5.07	8.67	5.39	6.18	5.39	5.35	7.41	12.23	7.845	8.38	12.77
76°C		1.621	2.40	4.165	2.37	2.83	2.37	2.2	2.92	5.18	2.289	3.07	5.68
82°C		0.765	1.21	2.132	1.04	1.34	1.04	0.913	1.18	2.23	0.501	1.13	1.85

Different Blend with Recycled LDPE and commercial PB

Figure A.3: Rutting resistance (G*/Sinδ) at high service temperature of rLDPE & PB modified binder



	P0B0	P2B0	P4B0	P6B0	P2B1	P4B1	P6B1	P2B1.5	P4B1.5	P6B1.5	P2B2	P4B2	P6B2
70°C	1.31	8.89	12.53	16.30	6.89	5.00	9.99	8.12	9.18	13.75	7.91	9.81	15.62
76°C		4.08	5.61	7.55	4.22	2.71	4.65	4.06	5.28	7.40	3.37	4.44	7.87
82°C		1.87	2.51	3.50	0.79	1.24	4.19	1.73	1.84	4.15	1.46	2.17	4.08

Figure A.4: Rutting resistance (G*/Sinδ) at high service temperature of rHDPE & PB modified binder

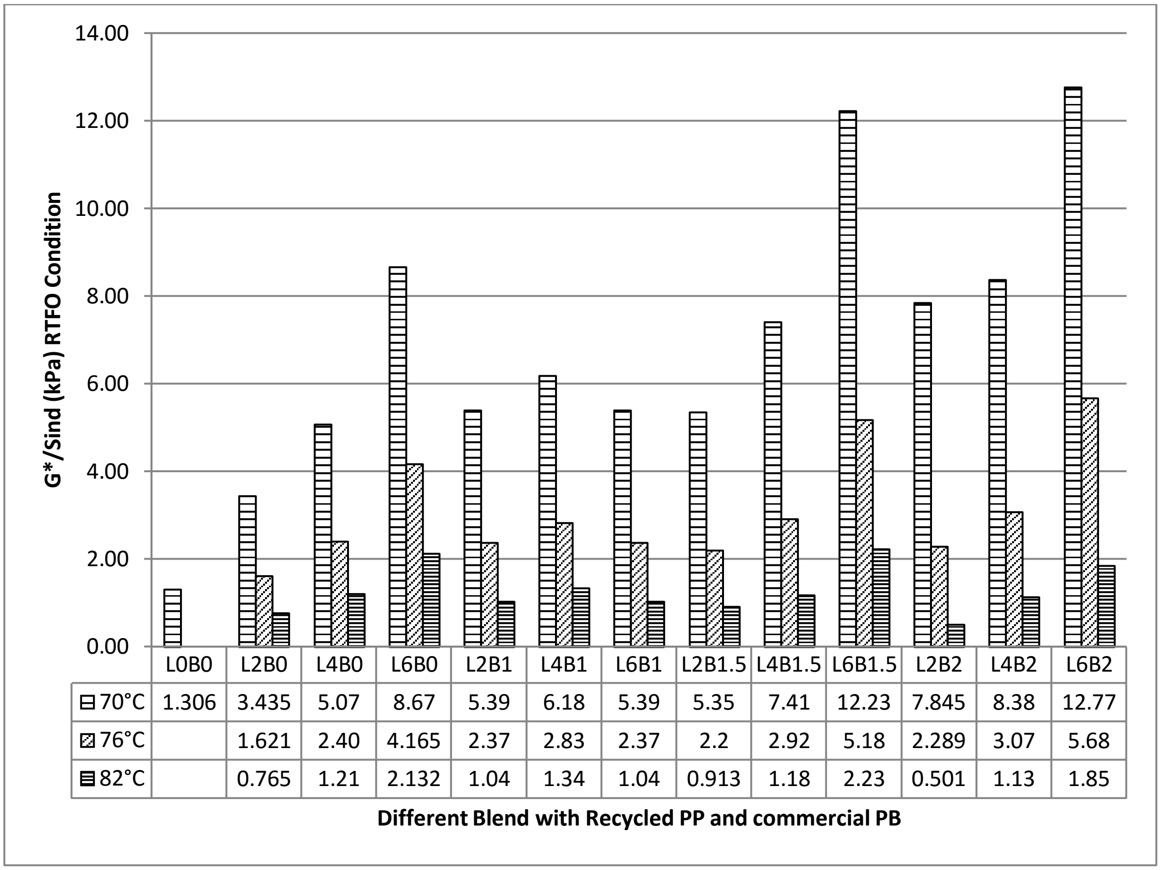


Figure A.5: Rutting resistance (G*/Sinδ) at high service temperature of rPP and PB modified binder

APPENDIX B

Viscoelastic Component Analysis from DSR Result

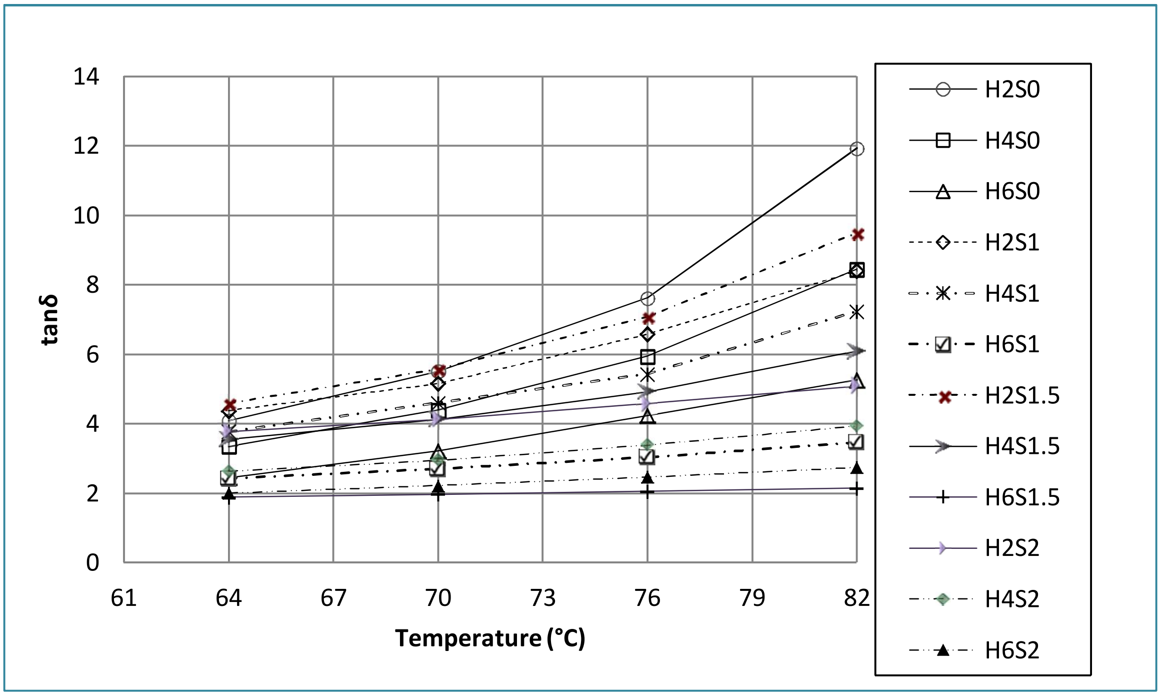


Figure B.1: Relationship between tanδ and temperature rHDPE modified binder

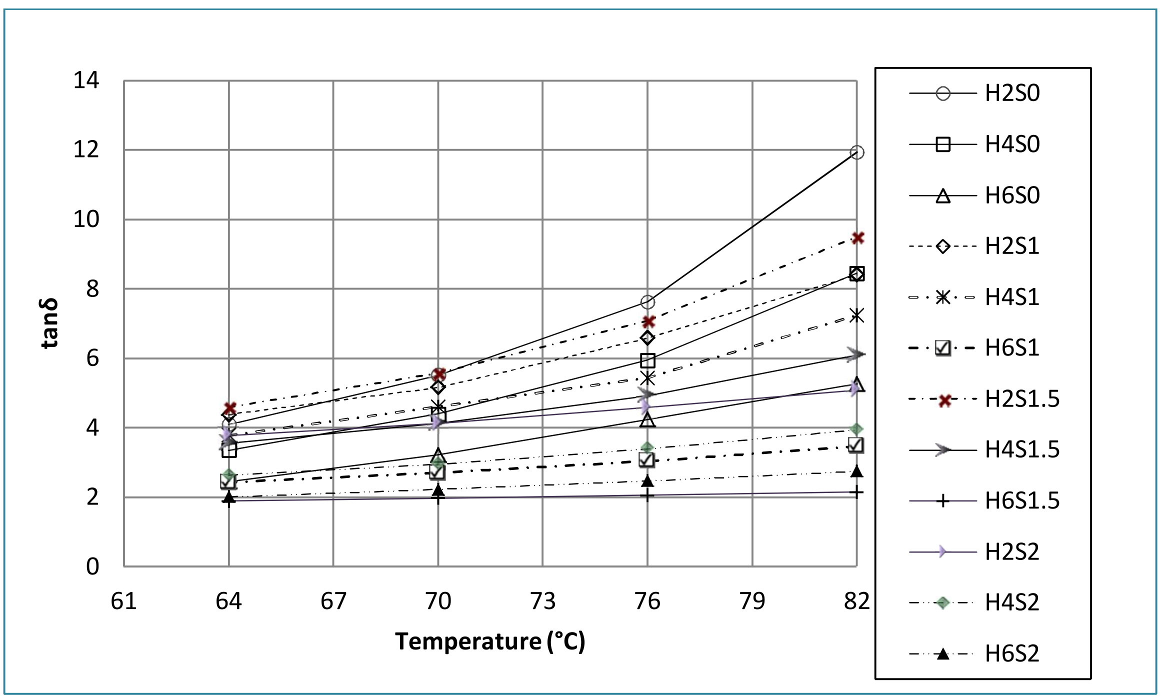


Figure B.2: Relationship between tanδ and temperature rPP modified binder

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