Laboratory Evaluation on Incompatibility of Waste-Polymer Modified Bitumen

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Certification

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Project Title (mention project title here)

Sustainable Development Goals

(Please tick the relevant SDG(s) linked with FYDP)

SDG No	Description of SDG	SDG No	Description of SDG
SDG 1	No Poverty	SDG 9	Industry, Innovation, and Infrastructure ✓
SDG 2	Zero Hunger	SDG 10	Reduced Inequalities
SDG 3	Good Health and Well Being	SDG 11	Sustainable Cities and Communities
SDG 4	Quality Education	SDG 12	Responsible Consumption and Production
SDG 5	Gender Equality ✓	SDG 13	Climate Change ✓
SDG 6	Clean Water and Sanitation	SDG 14	Life Below Water
SDG 7	Affordable and Clean Energy	SDG 15	Life on Land ✓
SDG 8	Decent Work and Economic Growth ✓	SDG 16	Peace, Justice and Strong Institutions
		SDG 17	Partnerships for the Goals ✓

Range of Complex Problem Solving			
	Attribute	**Complex Problem**	
1	Range of conflicting requirements	Involve wide-ranging or conflicting technical, engineering and other issues.	
2	Depth of analysis required	Have no obvious solution and require abstract thinking, originality in analysis to formulate suitable models.	
3	Depth of knowledge required	Requires research-based knowledge much of which is at, or informed by, the forefront of the professional discipline and which allows a fundamentals-based, first principles analytical approach.	
4	Familiarity of issues	Involve infrequently encountered issues	
5	Extent of applicable codes	Are outside problems encompassed by standards and codes of practice for professional engineering.	
6	Extent of stakeholder involvement and level of conflicting requirements	Involve diverse groups of stakeholders with widely varying needs.	
7	Consequences	Have significant consequences in a range of contexts.	
8	Interdependence	Are high level problems including many component parts or sub-problems	
Range of Complex Problem Activities			
	Attribute	**Complex Activities**	
1	Range of resources	Involve the use of diverse resources (and for this purpose, resources include people, money, equipment, materials, information and technologies).	
2	Level of interaction	Require resolution of significant problems arising from interactions between wide ranging and conflicting technical, engineering or other issues.	
3	Innovation	Involve creative use of engineering principles and research-based knowledge in novel ways.	
4	Consequences to society and the environment	Have significant consequences in a range of contexts, characterized by difficulty of prediction and mitigation.	
5	Familiarity	Can extend beyond previous experiences by applying principles-based approaches.	

Undertaking

I certify that the project **[Name of Project]** is our own work. The work has not, in whole or in part, been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged/ referred.

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Chapter 1

INTRODUCTION

EXECUTIVE SUMMARY

1.1 INTRODUCTION:

This executive summary provides an overview of modifying bitumen with waste polymer i.e. crumb rubber (CR) and overcoming the issue of incompatibility using additive i.e. Titanium Dioxide (TiO_2). Addition of crumb rubber enhances the physical and rheological properties of bitumen as the addition of CR causes the reduction in the values of penetration, ductility and increases the values of softening point and viscosity.

1.2 OVERVIEW:

The project "Laboratory Evaluation on the Incompatibility of Waste Polymers with Modified Bitumen" seeks to determine if adding waste polymers to modified bitumen for use in road building is feasible and what obstacles could arise. Reusing waste resources, including polymers, to create materials for road building has drawn attention due to its potential advantages for the environment and the economy as sustainable practices and waste management become more and more important.

This project's main goal is to assess waste polymers' suitability for usage with modified bitumen, a typical binder in asphalt mixtures. Waste polymers can be added to modified bitumen, which usually contains additives to improve its performance characteristics. This will help the bitumen perform better overall in a variety of environmental situations and increase its longevity and aging resistance.

Several methodical tests and analyses will be part of the laboratory-based examination. Initially, the waste polymers will be characterized, their chemical composition will be understood, and their physical qualities will be evaluated. Compatibility tests will next be carried out to identify the ideal blending ratios and processing parameters to produce a uniform and efficient polymer-modified bitumen.

The project's results will provide important new information on the possible advantages and difficulties of utilizing waste polymers in modified bitumen for road building. The findings might have an impact on the creation of sustainable infrastructure by providing a viable way to use waste materials in the building sector and solving environmental issues with polymer disposal at the same time.

1.3 ABSTRACT:

Accordingly, due to environmental challenges, engineers and researchers sought to use crumb rubber waste in engineering projects as a contribution to preserving the environment. Modifying bitumen with crumb rubber waste is one of the common approaches to reduce the amount of global crumb tire waste. It is documented that amending bitumen with crumb rubber waste significantly enhance the physical and rheological properties of bitumen. Otherwise, one of the main challenges facing researchers regarding modification bitumen with crumb rubber waste is incompatibility. The occurrence of incompatibility is attributed to the difference in the density and polarity between plastic and bitumen. In addition, incompatibility negatively affect the performance of the asphalt layer, which, in turn, significantly decreases the lifespan of asphalt layer. Furthermore, modifying bitumen with crumb rubber waste poses a significant challenge for asphalt mixing plants due to the high viscosity of crumb rubber-modified bitumen, which requires an increase in mixing energy to achieve homogeneity. The increase in the energy of mixing may increase the cost of production, which is considered a challenge in modifying bitumen with crumb rubber waste. Therefore, this project is aimed to introduce novel contributions in terms of eliminating the drawbacks of modifying bitumen with crumb rubber waste in terms of incompatibility and high viscosity of crumb rubber-amended bitumen. However, in this project, the crumb rubber-modified bitumen will further be amended with the additive of titanium dioxide to improve compatibility and decrease viscosity.

1.4 INTRODUCTION TO BITUMEN:

It is well known that bitumen binder, which provides adhesive strength to bind loose mineral grains together, is one of the most crucial components of the bitumen mixture. Therefore, the bitumen binder's properties are essential to the mixture's performance on the road. Additionally, rheological, and physical indices are used to assess bitumen binder. In contrast, bitumen binder is viscoelastic and readily affected by temperature changes in the surrounding area. Furthermore, physical indicators of bitumen binder qualities, such as penetration, softening point, and ductility, are only partially indicative of these capabilities at a given temperature. Rheological indices, on the other hand, may represent the viscoelastic properties of bituminous material in actual service conditions. Thus, studies of bitumen binder's rheological characteristics are typically carried out to forecast its performance.

1.5 INTRODUCTION TO CRUMB RUBBER:

Tires are intricately engineered items meant to withstand high loads, temperatures, and threats from germs, sunshine, ultraviolet radiation, oil, and acids. Tire materials, however, are not favourable for secondary post-consumer use, which makes recycling more difficult. The primary components of a tire include metal, cloth, carbon black, natural and synthetic rubber, and additives. The manufacturer often treats the precise composition, which varies depending on the tire's size and application, as secret information. Approximately 47% rubber/elastomer, 21.5% carbon black, 16.5% steel, 5.5% Fiber, 1% zinc oxide, 1% sulphur, and 7.5% additives are found in a typical trash tire from a passenger automobile. Depending on whether they are from passenger vehicles or trucks, and depending on whether they are meant for summer or winter weather, tires have somewhat different compositions.


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Tires nearing their end of life (ELTs) pose a serious environmental threat. Approximately 1.5 billion tires reach the end of their useful lives annually, and the figure is rising [1]. Regretfully, the great majority of tires are burnt or landfilled globally, which has disastrous ecological effects. They specifically provide a major risk to human health (e.g., fire and pests). Furthermore, landfills are often the least expensive disposal option in most countries. The Europe Union (EU) outlawed ELT dumping in Europe in 2006, necessitating the deployment of alternative recycling and reuse strategies.

Another alternative for getting rid of ELTs is energy recycling, which is what Switzerland is doing right now. This entails turning them into tire-derived fuel (TDF), which is then used in industrial power plants in place of fossil fuel. Nevertheless, non-burnable tire waste and pollutants.. [1]

Shredded Form of tires (Crumb Rubber)

1.6 BACKGROUND OF THE STUDY:

The technique of CR asphalt alteration is still not widely used, despite its obvious benefits. Approximately 4000000 tons of asphalt concrete, or 200000 tons of bitumen, are used annually in Switzerland to construct or renovate road pavements (Neulandmagazin). In theory, using 15% CR to change 50% of the needed bitumen would take 10500t of waste tire rubber annually, or 0.7 million car tires. [1]

The usual term for the tire rubber components used to alter asphalt binder is Crumb Rubber (CR). The usage of CR modified asphalt has emerged as a crucial tire waste recycling method due to rising environmental consciousness. The two procedures that are often used to integrate CR into asphalt mixes are called the wet process and the dry process. CR serves as an asphalt binder modifier in the wet process and as part of the fine aggregates in the dry process.

Crumb Rubber Powder

1.7 APPLICATION OF CRUMB RUBBER IN ASPHALT INDUSTRY:

The best method of disposal is tires material recycling in its entirety. The first process involves grinding the tire into granules with diameters varying from 5 to 50 mm. The granule is then employed as an addition in various goods for the rubber, plastics, and civil engineering sectors. The application of crumb rubber (CR) in the asphalt industry is of special importance in this case. With the CR, the bituminous binder of asphalt concrete may be altered to enhance its characteristics. By taking use of the rubber's flexibility and ability to reduce noise, this change can improve road safety and longevity while lowering noise pollution.

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1.8 ADVANTAGES OF CRMB:

- ✓ It's been demonstrated that the viscosity of the binder rises with the quantity of crumb rubber component. Greater viscosity has the advantage of allowing for the addition of more binder to the asphalt mix, which improves the binder's resistance to temperature changes and long-term durability while reducing reflective cracking, stripping, and rutting.
- ✓ The rheological responsiveness of the binder was also altered by the addition of CR. In particular, the inclusion of CR increased the material's resilience to heat cracking and rutting. [2]
- ✓ Furthermore, compared to traditional pavement technology (such as SBS modified bitumen pavement), Wang and Xiao discovered that CRMB pavement technology might minimize environmental impacts by 5% to 10% during construction. In the

meanwhile, the life cycle evaluation suggests that a large decrease in greenhouse gas emissions may also be achieved during the maintenance period. Therefore, CRMB pavement technology application and promotion are now ongoing.

- ✓ It is well known that bitumen binder, which provides adhesive strength to bind loose mineral grains together, is one of the most crucial components of the bitumen mixture. Therefore, the bitumen binder's properties are essential to the mixture's performance on the road. Additionally, rheological, and physical indices are used to assess bitumen binder. In contrast, bitumen binder is viscoelastic and readily affected by temperature changes in the surrounding area.
- ✓ Furthermore, physical indicators of bitumen binder qualities, such as penetration, softening point, and ductility, are only partially indicative of these capabilities at a given temperature. Rheological indices, on the other hand, may represent the viscoelastic properties of bituminous material in actual service conditions. Thus, studies of bitumen binder's rheological characteristics are typically carried out to forecast its performance.
- ✓ CRMB pavement has great mechanical properties and pavement performance during service, including rutting resistance, anti-cracking at low temperature, fatigue crack and water damage resistance. And 40%-88% reduction of driving noise can be achieved by CRMB pavement in comparison with conventional pavement.[3]
- ✓ Crumb rubber in asphalt pavement transfers the property of elasticity. According to research, the modification of bitumen by crumb rubber at high temperature increases the complex modulus of the binder while reducing the phase angle which influences resistance to rutting.
- ✓ The advantages of this kind of bitumen modification for engineering are well-established and have been known for many years in the global community. Like other bitumen products treated with polymers, the product is still not extensively utilized and approved in the pavement sector. The primary causes of this are a few constraints, including consistency and uniformity before and after the manufacturing phases, respectively, and the lack of a breakthrough in the form of a stable modified bitumen that preserves the product's qualities.
- ✓ Crumb rubber in asphalt pavement transfers the property of elasticity.

- ✓ According to research, the modification of bitumen by crumb rubber at high temperature increases the complex modulus of the binder while reducing the phase angle which influences resistance to rutting.
- ✓ The advantage of crumb rubber modified asphalt pavement is that it is durable, resistance to permanent cracking and thermal deformation. The incorporation of CR reclaimed from waste tires has resulted in enhanced properties in conventional bitumen. The engineering benefits from such a modification of bitumen are very well proven and have been recognized around the world for decades. [3]
- ✓ Most of the virgin bitumen lacks the necessary qualities, which leads to problems. Modifiers are used to enhance the rheological qualities of bitumen by combining it with polymers such as rubber and plastic. The failures are caused by severe loads and temperature change. Numerous modifications have been employed by researchers to improve the characteristics of asphalt, but doing so also raises the price of pavement. trash material that is widely available and would be a solution to non-biodegradable trash, such as crumb rubber, should be used to discover a sustainable solution. [4]

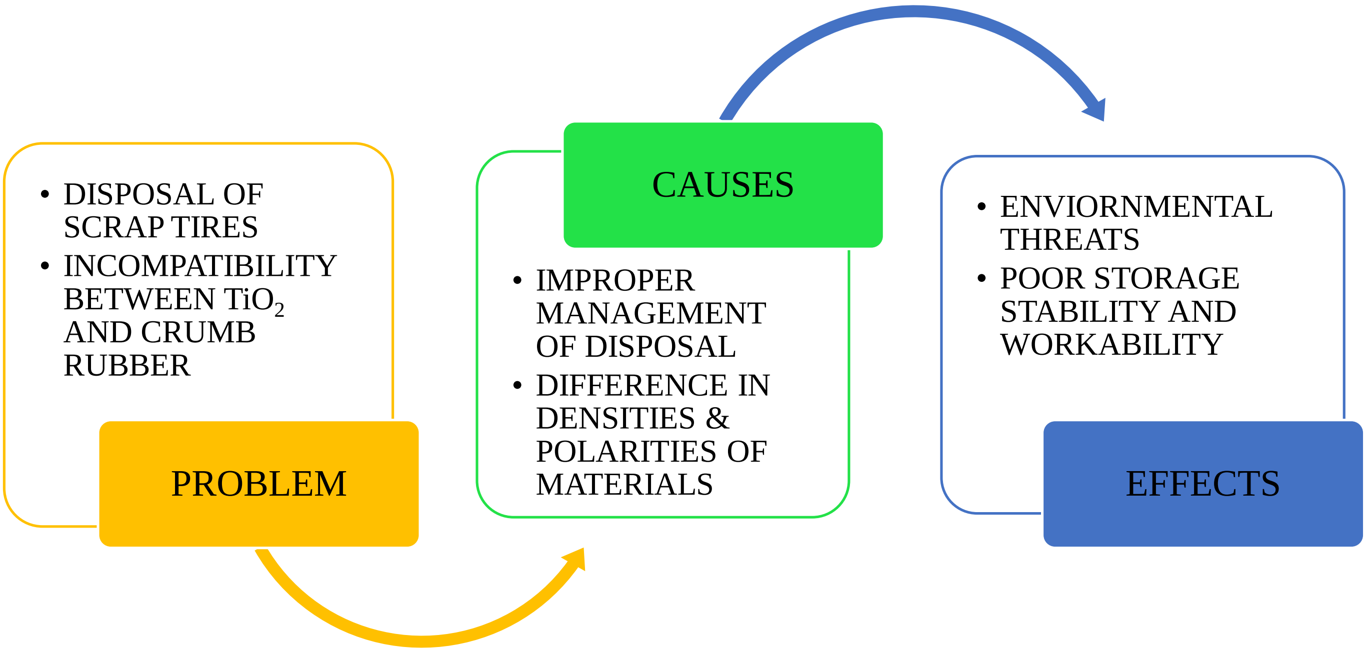
Furthermore, compared to traditional pavement technology (such as SBS modified bitumen pavement), Wang and Xiao discovered that CRMB pavement technology might minimize environmental impacts by 5% to 10% during construction. In the meanwhile, the life cycle evaluation suggests that a large decrease in greenhouse gas emissions may also be achieved during the maintenance period. Therefore, CRMB pavement technology application and promotion are now ongoing.

When CRMB exhibits poor high temperature rheological characteristics, it becomes pliable and weak in its ability to withstand deformation at elevated temperatures. This can result in various pavement distresses, such as bleeding and rutting, which can shorten the pavement's service life and cause significant financial losses. The effects of the less smelly CR on the high-temperature rheological characteristics of CRMB, which is made from several bitumen sources, are yet unknown, nevertheless. [4]

1.9 PROBLEM STATEMENT:

Approximately 1.5 billion tires reach the end of their useful lives annually, and the figure is rising. Regretfully, the great majority of tires are burnt or landfilled globally, which has terrible ecological effects. They especially seriously endanger human health. Tires are complex engineered items meant to survive high loads and temperatures, as well as assaults from bacteria, UV radiation, oil, and acids. Tire materials, however, are not good for secondary post-consumer usage, which makes recycling more difficult. [1]

On the other hand, the main problem with modifying bitumen with plastics is incompatibility in which the difference in density and polarity between bitumen and waste materials produce significant changes in the physical and rheological properties of bitumen, which in turn, negatively affect the performance of modified bitumen.



1.10 AIMS:

The aim of the project is to reduce incompatibility between crumb rubber and bitumen by adding titanium dioxide.

ENHANCEMENT IN THE PHYSICAL AND RHEOLOGICAL PROPERTIES OF BASE BITUMEN.

TO REDUCE INCOMPATIBILITY BETWEEN BITUMEN AND CRUMB RUBBER.

TO LIMIT THE DISPOSAL OF SCRAP TIRES.

OVERCOMING THE ISSUE OF INCOMPATIBILITY BETWEEN BITUMEN AND CRUMB RUBBER BY THE USE OF TITANIUM DIOXIDE.

1.11 OBJECTIVES:

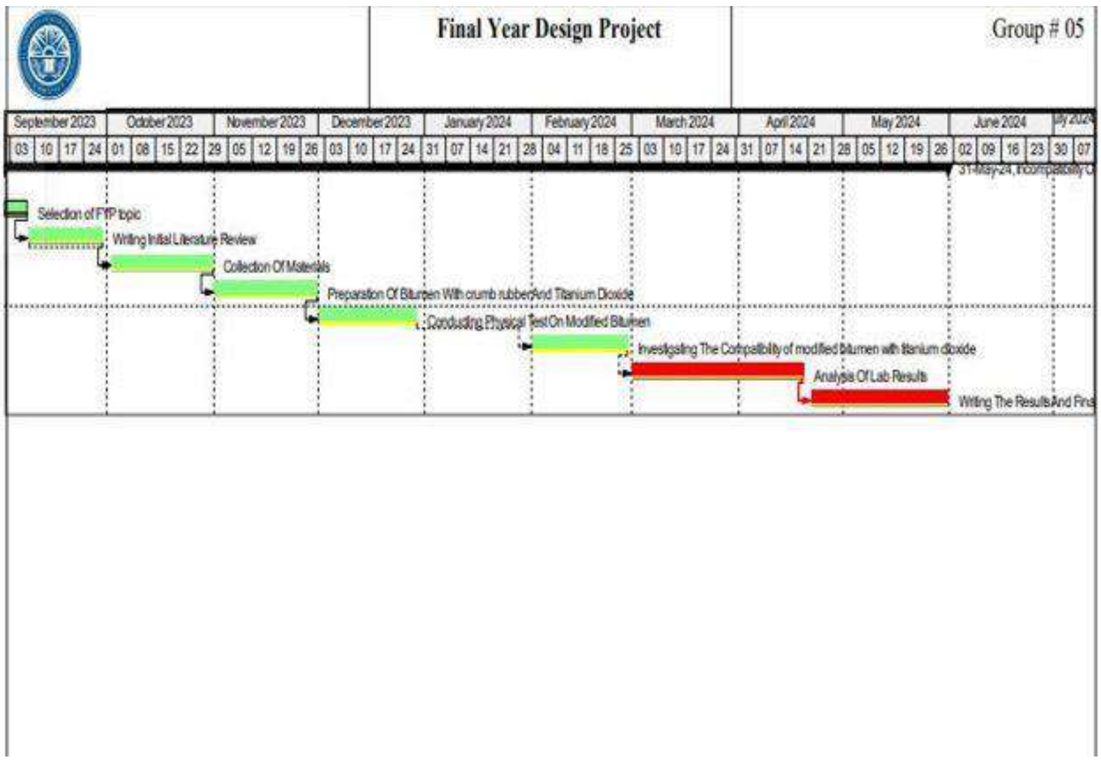
TO ENHANCE THE RHEOLOGICAL PROPERTIES OF BITUMEN BY USING CRUMB RUBBER.

TO STUDY THE CHANGES IN THE PHYSICAL PROPERTIES OF BITUMEN BY INCOPORATING DIFFERENT PERCENTAGES OF CRUMB RUBBER (5%, 10%, 15%).

TO INVESTIGATE THE EFFECT OF MODIFYING BITUMEN WITH WASTE POLYMER BY THE MEANS OF STORAGE STABILITY TEST.

1.12 MATERIALS:

1.12 PROJECT TIMELINE:



Chapter 2

CHAPTER 02

LITERATURE REVIEW:

They demonstrated the enhance in the engineering properties of bitumen when they modified it by using Crumb Rubber (CR) along with Styrene Butadiene Styrene (SBS). Their main focus was to enhance the engineering properties of bitumen and to limit the generation and disposal of scrap tires which was an environmental threat. Inclusion rate of SBS and CR was 2% - 5% and 4% - 10% respectively. They performed series of laboratory experiments so to investigate the changes in the engineering properties of bitumen. These tests included Penetration test, Softening point test, Viscosity test, Ductility test, and Dynamic Shear Rheometer (DSR) test. They found out that with the increase in the dosage of CR and SBS, the penetration resistance and softening point improved. By conducting Penetration test, they demonstrated that modified bitumen mixes with (2% SBS & 10% CR) and (3.5% SBS & 11.03% CR) had the lowest penetration value and the highest softening point respectively. They concluded that addition of CR and SBS increased penetration resistance by 24.06%. Conducting the Viscosity test, they concluded that the viscosity of modified bitumen enhanced and increased with the increase in the dosage of CR and SBS. The modified mixture having (3.5% SBS & 11.03% CR) was having highest viscosity. The addition of CR and SBS slightly increased the bitumen's extensibility with the mix having (3.5% SBS & 11.03% CR) had the ductility of 78mm. They conducted DSR test which showed an increase in complex moduli and phase angle of bitumen. They concluded that the optimum content of SBS was 3.5% and for CR it was 11.03%. (Ganapathy, G.P. et.al, 2022) [5]

They demonstrated the enhance in the engineering properties of bitumen by modifying it with Natural Rubber (NR) latex and Crumb Rubber (CR). Their main focus was to enhance the rheological, physical properties of bitumen and to improve the durability of the asphalt pavement. They performed a series of laboratory experiments which included Penetration Test, Softening Point Test, Ductility Test and Dynamic Shear Rheometer (DSR) test. The rubberized bitumen was prepared with 4%, 6%, & 8% concentrations of NR latex and CR. They concluded that there was decrease in the penetration value and increase in softening point by the inclusion of NR and CR. The ductility was decreased with the addition of NR while decreased with the addition of

NR. The rutting resistance of CR modified bitumen increased as content of CR kept on increasing whereas the rutting resistance of NR modified bitumen increased up to 4% and after that decreased. Optimum content of CR was found out to be 8% and of NR latex was 4% at which the complex modulus and rutting resistance of the rubberized bitumen was improved. (Al-Sabaeei, A. M. et.al, 2020) [6]

They demonstrated the improvement and changes in the engineering properties of bitumen by modifying it with the Crumb Rubber (CR). They converted CR in the pyrolyzed oil using pyrolysis protocols. Their main focus was to overcome the pavement failures and exponential deteriorations caused by heavy loads, temperature variations and weather changes. They performed series of laboratory test which included Penetration Test, Softening Point Test, Flash and Fire Point Test, Viscosity Test, Storage Stability Test and Thermogravimetric Analysis Test (TGA). A comparative study was made between Crumb Rubber Modified Bitumen (CRMB) and Crumb Rubber Pyrolized Modified Bitumen (CRP. MB) in order to investigate the changes in engineering properties of bitumen. The dosage rate CR in bitumen was 0%, 10%, 12.50% 15%, 17.50%, 20% and 22.50% whereas pyrolized crumb rubber oil was added about 2%. They demonstrated that by the use of pyrolized oil, up to 20% of CR can be easily blended with bitumen. Low temperature was required for blending. They concluded that by the use of CRP. MB, the viscosity and softening point of bitumen increased while penetration value decreased which showed resistance to deformation. CRP. MB had better storage stability as compared to CRMB. (Shaikh, A. et.al, 2023) [7]

They demonstrate the enhancement in the engineering properties of bitumen by modifying it with the combination of Crumb Tire Rubber (CTR) and Waste Cooking Oil (WCO) known as Waste Rubber Oil (WRO). Their main focus was to improve properties of bitumen and to improve the poor storage stability and workability which effect the service performance of the pavement. They prepared WRO by blending 300g of CTR and 200g of WCO following by the light pyrolysis at a constant pressure and temperature of 280ºC for 2 hours. Then they prepared the rubberized bitumen by mixing 18% CTR by weight of bitumen. After this they carried out a series of laboratory test which included Penetration Test, Softening Point Test, Ductility Test, Viscosity Test and Storage Stability Test. They concluded that WRO enhanced the storage stability and reduced the resistance to shear damage and deformation at high temperatures. The WRO modified bitumen had the lower complex modulus and resistance to rutting as compared to rubberized bitumen but it improved the plasticity and workability of the bitumen. (Dong, R. et.al, 2018) [8]

They enhanced the engineering properties of bitumen using Polyethylene Glycol (PEG) and Titanium Dioxide (TiO_2). Their main focus was to modify and enhance the engineering properties of bitumen using PEG and TiO_2. They carried out their research in two phases. In the first phase, bitumen was blended with PEG in different proportions. These proportions were 2%, 4%, 6% and 8%. Then they conducted series of laboratory test which included Penetration Test, Softening Point Test, Flash and Fire Point Test, Ductility Test and X – Ray Diffraction (XRD) to see the changes in bitumen. Then in second phase, different percentages of TiO_2 were incorporated which were 1.5% and 3%. Then same tests were conducted to see the changes in the bitumen. The optimum PEG content was 6%. They concluded that there was a decrease in the penetration and ductility with increasing content of PEG which shows higher resistance towards rutting. The increase in PEG content causes increase in softening point. Flash and Fire points attain their maximum value at 6% while addition of TiO_2 caused decrease in penetration and ductility values. By performing XRD analysis, they concluded that TiO_2 causes an increase in interlayer spacing value (d). (Naeem, J. et.al, 2023) [9]

They produced crumb runner through ambient mechanical grinding and cryogenic grinding. Recommended CR content for wet method was 10% of binder weight without additives and 30% with additives. For dry method it was 1.5% of mixture weight without additives and 3% with additives. CR increases optimal bitumen content because CR particles absorb some bitumen constituents. They concluded that CR increase asphalt viscosity. It also improves the physical properties like reducing penetration and increasing softening values. Also enhances rheological properties by increasing the stiffness and rutting resistance and reducing phase angle. (Bilema, M. et.al, 2023) [10]

They used special additives like SBS or organic fibers for modification of bitumen. Asphalt Rubber (AR) performed much better than the conventional mixtures with the same aggregate blend. Reuse of rubber originated from end of life tires can lead to significant benefits of environmental impacts and minimization of resource depletion. In terms of direct cost, it can be said that AR is 20-30% more than the cost of conventional mixture but AR is much more durable than conventional mixtures. (Picado-Santos, L. et.al, 2020) [11]

This study covers the impact of crumb rubber on the rheology of crumb rubber modified bitumen (CRMB) and examines some of the worldwide standards for generating CRMB. The review demonstrates how the rheology of CRMB is influenced by both external and internal variables, including temperature, mixing duration, and modification process, as well as internal variables such crumb rubber amount, particle size, and pure bitumen composition. Gel permeation chromatography analysis shows that a higher proportion of crumb rubber (15% to 20%) in the bitumen contributes to the reduction of large molecular size value of the binder. This is due to the ejection of lighter constituents that were earlier absorbed by the rubber from the bitumen. It is recommended 15% to 20% crumb rubber addition for a significant improvement in aging effects, creep stiffness, and economic factors. On the other hand, showed that 10% of CRM addition increased the performance grade of bitumen from 64◦ C to 70◦ C and 15% CRM addition increased at least two high temperature performance grades from 64◦ C to 76◦ C. At higher temperatures, the viscosity of CRMB was found to increase quite dramatically.

They compared to binder that was mixed at 177◦ C, at 200◦ C the viscosity is 5% higher, and at 223◦ C the viscosity increased 41%. With regards to the blending time, it was found that the viscosity of binder that was mixed for 5 minutes increases 11%, while at 480 minutes the viscosity increased to 46%. On the other hand, the failure temperature between binder mixed at 177◦ C and 200◦ C was found to be negligible. Nonetheless, the maximum and lowest permitted void content limits of 18% and 25% are near the lower and higher bounds of the optimal binder content, which are 5% and 7%. As a result, for practical purposes, the ideal binder concentration should be somewhere in the range of 6% and 6.5% to provide a high-quality product while also permitting a certain amount of tolerance during the production of rubberized bitumen.

It has been demonstrated that bitumen modified with crumb rubber improves bituminous binder properties such viscosity, softening point, loss modulus, and storage modulus. As a result, the pavement's resilience, rutting resistance, and fatigue cracking resistance are all improved.[Ibrahim, M. R et al] [12]

This study examines the Marshall mix, Superpave Gyratory compacted CR-modified, and conventional asphalt concrete combinations using laboratory and field evaluation methods. The field analysis quantified the observed improvement in pavement performance because of the treatment, whereas the laboratory analysis assessed the mechanistic parameters: MR, permanent deformation, and indirect tensile strength. The outcomes demonstrated and measured the degree to which CR enhanced conventional mixture performance with respect to the specified performance criteria. This method was in line with earlier, comprehensive laboratory research and field study that demonstrated how CR modification produces considerably smoother asphalt pavement mixtures and increases resilience to rutting and cracking when compared to mixtures created with traditional asphalt binder. This method was in line with earlier, comprehensive laboratory research and field study that demonstrated how CR modification produces considerably smoother asphalt pavement mixtures and increases resilience to rutting and cracking when compared to mixtures created with traditional asphalt binder.

- The Marshall stability test indicated that the strength of the CR specimens increases as compared to the conventional specimens. An increase of about 29 and 31% was observed with 60/70 and 80/100 penetration grade modified binders, respectively.
- The tensile strength of the CR specimens compared to the conventional specimens was not much higher using both the grade modifications.
- The MR of the CR specimens compared to the conventional specimens was 34% higher for 60/70 grade and 53% higher for 80/100 grade.
- The permanent deformation (rutting) test results revealed that the least rutting was observed for the 8% CR with 60/70 grade and the 12% CR for 80/100 grade modified mixtures.

Crumb Rubber is an effective additive and is suitable for use in locations prone to severe rutting.[Irfan, M., Ali et al] [13]

Their research includes two traditional methods which were dry process and wet process. Although dry process has greater advantages including more crumb rubber usage, conservation of natural resources and so on, but there is less desire to apply dry process compared to wet process because of its poor performance. They replaced conventional filler with 20%, 40% and 60% CRP by weight of filler. They performed Indirect tensile stiffness modulus (ITSM), Moisture susceptibility test, Repeated load axial test, Wheel track test and four point bending beam fatigue test. They concluded that the use of crumb rubber powder (CRP) as filler can reduce the resistance of asphalt mixes against moisture damage. The highest and lowest moisture resistance was obtained at 20% CRP + 2H and 60% CRP mixes, subjecting the 60% CRP mix to 2H curing time, the moisture resistance of this mix was enhanced up to 77%. Replacement of 20% filler with CRP increased the stiffness modulus. Using CRP filler with curing process enhanced the ability of asphalt mixes to recover plastic deformation. Higher contents of CRP had inverse effect on the fatigue performance. Curing process could be effective in improvising the cohesion, and interface adhesion between the binder film and the aggregate. The use of large quantity of waste tires substituting natural aggregates in asphalt mixtures represents a great advantage from sustainability point of view. (Seyed Amid Tahami et al., 2019) [14]

Another research included rubber asphalt RA samples with 15–35% of rubber content, 170–230 ◦C of reaction temperature, 8–225 min of reaction time and 0–10% of aromatic oil (AO) content were prepared. The study was conducted by micro and macro tests, and the fundamental properties were explored. The results showed that the crumb rubber in 15–35% RA only swells at 170 ◦C, while the crumb rubber swells first and then degrade at 190–230 ◦C. t. The higher rubber content means higher softening point, ductility, elastic recovery and lower penetration of RA. Higher reaction temperature means higher penetration, ductility and lower softening point of RA. With the increase of AO content of RA, the penetration and ductility increase while the softening point and the elastic recovery decrease. The storage stability of RA decreases with the increase of rubber content and the decrease of reaction time as well as the AO content. The complex modulus increases while the phase angle decreases when swelling is dominant, and the complex modulus decreases while the phase angle increases when degradation is dominant. The high temperature rutting resistance of RA increases with the increase of rubber content and the decrease of (Yajing Zhu et al., 2022) [15]

Crumb rubber modified bitumen (CRMB) has excellent high-temperature performance and fatigue resistance, and is widely used in asphalt pavement to cope with increasing traffic axle load and changing climate. working performance of CRMB and CRRB in high-temperature and low temperature conditions were studied through physical and working performance testing of bitumen. The CR and SCR were tested by scanning electron microscope (SEM), Fourier transform infrared spectrometer (FTIR), gel permeation chromatography (GPC), and particle size distribution (PSD) tests to study the physicochemical behavior and microscopic effects before and after CR swelling. CR dosage was in the range of 10%, 15%, and 20%. CR dosages have a positive effect on the high- and low-temperature performance, storage stability, and elastic recovery of bitumen. CR improved the ultra-low temperature crack resistance of bitumen. After swelling, the CR particle size increased and the range became wider, the surface complexity of CR became higher, and the specific surface area was larger. At the same time, CR carried out the transformation process from large and medium molecules to small molecules. During the swelling process, a new benzene ring structure appeared in the CR, and the C–C bond and C–S bond of CR broke, forming part of the C=C bond. Cr significantly improved the high temperature resistance of bitumen. The high temperature failure temperature of 10% CRMB was 30.62% higher than that of 70# base bitumen, and its high temperature PG grade rapidly improved by four grades. CR raised the viscosity of bitumen, resulting in a significant increase in mixing and compaction temperatures, which can be mitigated by the addition of warm mixes. (Hongbin Zhu et al., 2022). [16]

Chapter 3

3.1 REEARCH METHODOLGY:

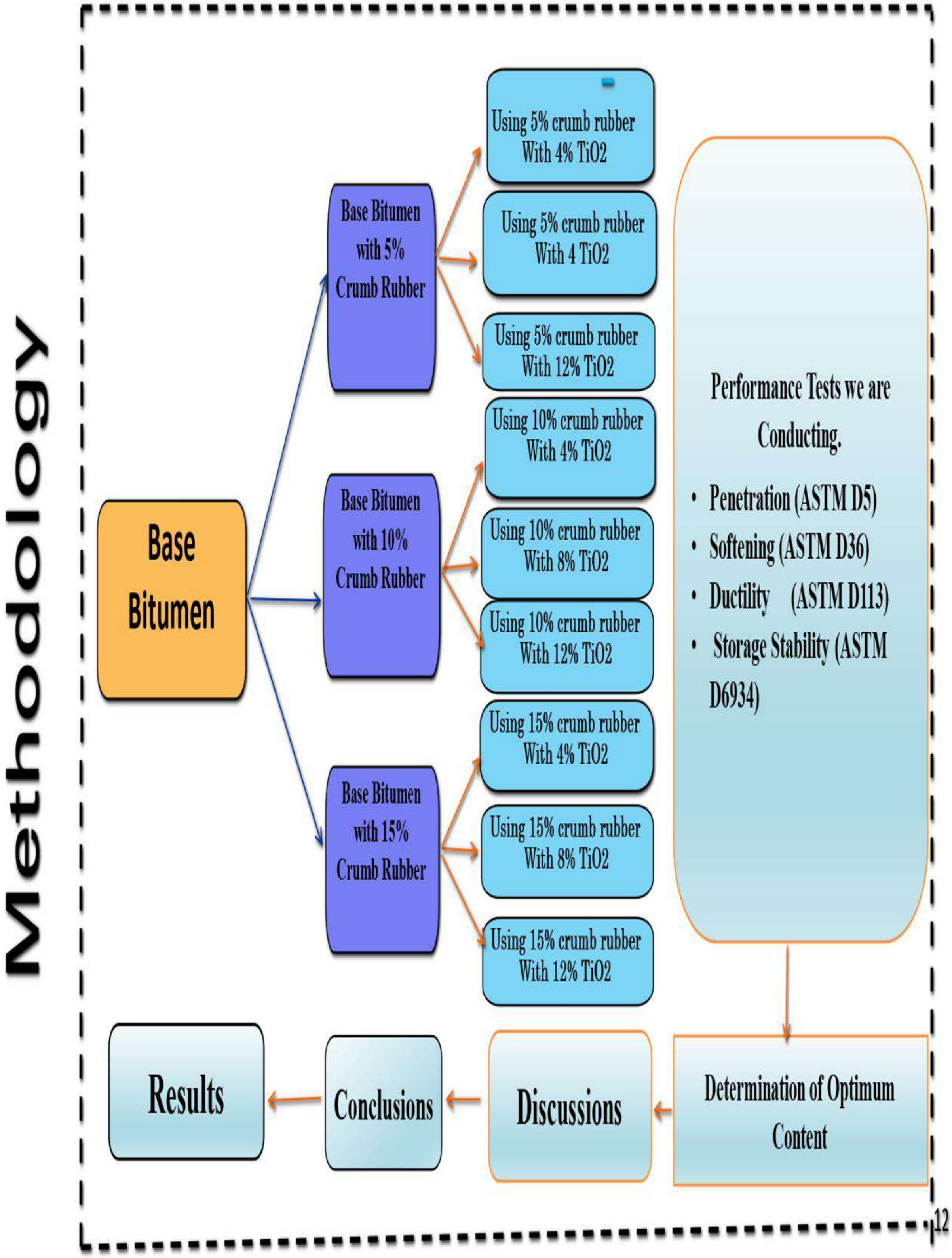
Our research methodology consists of the Laboratory evaluation of the Bitumen with the waste of the polymer (Crumb Rubber), modified bitumen sampling and lab testing after which our initial results were compiled from these lab tests. Based on these tests we were able to know about our research and conclusion from these results. We used the parent Bitumen for analysing the results with the Modified Bitumen which were blended and mixed with crumb rubber and to overcome the incompatibility we used the Titanium Dioxide (TiO_2).We incorporated the Lab tests. These tests were Basically Penetration test, Ductility, softening, Viscosity and Storage stability Test. The penetration test gives us the grade of the bitumen. While the ductility test tells us about the Ductile behaviour of the Bitumen and most prominent Storage stability, that is our most prominent test tells us about the compatibility between the crumb rubber and Bitumen.

We performed these following tests:

- Penetration Test
- Softening Point
- Ductility Test
- Viscosity Test
- Storage Stability Test

In the last stage of the Methodology Storage Stability Test was performed to check the How much compatibility is achieved from the following tests. At the start of the testing our lab work 1st of all we performed the physical test on the parent Bitumen and then blended the with the 5% of the crumb rubber performed these results again and checked the results and compared with the original one. After these results we make 3 samples from the Sample of 5% blended with crumb rubber and taking 3 equal samples from the sample and then we Added the Titanium dioxide TiO_2 in each sample with different percentages like that of 4,8 and 12%. After that we gain mixed each sample separately and again performed the lab tests and analysed them with the previous test results. We added TiO_2 to overcome the incompatibility issue between the Crumb rubber and

Bitumen. Actually the ratios and Different percentages of Titanium dioxide will make a trend and we will be able to distinguish at which we have resolve the issue of the incompatibility issue and how far we are succeeded in our results.



3.2 LAB TESTING:

3.2.1 MIXING:

After performing the initial test on the Bitumen we obtained the different samples of the Bitumen and blended it with different percentages of the crumb rubber like we blended the parent Bitumen with the 5%,10, and 15% crumb rubber in as a separate sample for our testing and blended each sample of crumb rubber with the Bitumen with Blending machine by heating it to the 150 C and by continuously stirring. We Blended each sample of the crumb rubber and Bitumen for at least 30 minutes by providing heating with the help of the Hot Magnet Plate

3.2.2 DUCTILITY TEST (ASTM D113):

The ductility of a bituminous material is measured by the distance to which it will elongate before breaking when two ends of a briquette specimen of the material, of the form described, are pulled apart at a specified speed and at a specified temperature. Unless otherwise specified, the test shall be made at a temperature of 77 ± 0.9^0F (25 ± 0.5^0C) and with a speed of 5 cm/min $\pm$ 5.0%. At other temperatures the speed should be specified. This test method provides one measure of tensile properties of bituminous materials and may be used to measure ductility for specification requirements.

EQUIPMENTS:

- Mold
- Water Bath
- Testing Machine
- Thermometer
- Water
- Petrol

PROCEDURE:

1. Assembled the mold.

2. Coated the surface of mold with glycerin or talc (to prevent the material from sticking).

3. We heated the sample until it becomes fluid.

4.We poured the material into the mold.

5. We leave the mold at room temperature for 30/40 minutes.

6 We Put the mold in the bathtub.

7 We removed the briquette from the tub after 80/90 minutes.

8. Tested the briquette.

9.The sides of the mold are now removed, and the clips are carefully booked on the machine without causing any initial strain.

10.The machine is started, and the two clips are thus pulled apart horizontally.

11. The distance at which the bitumen thread of each specimen breaks, is recorded (in cm) to report as ductility value.

CALCULATION & INTERPETATION:

Grade of Bitumen ………60/70……………………

Pouring temperature………25 °C………………….

Period of cooling in room………25°C …………

Water bath temperature…………25°C …………

PRECAUTIONS:

- We carefully heated the sample to prevent local overheating.
- We Took care not to disarrange the parts and thus distort the briquette.
- The water in the tank of the testing machine shall cover the specimen both
- above and below it by at least 2.5 cm
- Keep the water bath and the specimen at the specified temperature for the specified
- Pulling of the two clips apart should be at a uniform speed.

Ductility of Bitumen tell us about

i. Tensile strength of bitumen
ii. Ductility grade

The ductility value gets seriously affected if any of the following factors are varied:

i) Pouring temperature
ii) Dimensions of briquette
iii) Improper level of briquette placement

Rate of pulling Increase in minimum cross section of 10sq.mm and increase in test temperature would record increased ductility value. The ductility values of bitumen vary from 5 to over 100.

3.2.3 PENETRATION TEST:

This test is used to determine the penetration grade of bitumen. The behavior of bituminous materials varies significantly with change in temperature. It is therefore important to use the appropriate grade of bitumen that is best suitable for the climatic conditions of the project area. The penetration of bitumen is defined as the distance in tenths of millimeter that a standard needle vertically penetrates in a sample of bitumen under known conditions of loading, time and temperature. (A load of 100 grams applied for 5seconds at 25□C is standardized for the test) A small penetration value indicates that the bitumen is hard, while the high penetration value indicates that the bitumen is soft.

APPARATUS:

- Penetrometer with control box.

- Container. 55 mm diameter and 35 / 70 mm internal height. Should have flat bottom.
- Water bath with at least 10 liter capacity.
- Heater
- Thermometer
- Penetration Needle
- Transfer tray
- Timing Device

PROCEDURE:

- We heated and Softened the bitumen by heating it up to 90°**C** to bring it to pouring consistency. Stirred the bitumen while heating to avoid local overheating and to make it too homogenous.

- Poured the bitumen into container to a level that when cooled to testing temperature, depth of bitumen should be at least 10 mm more than the expected depth of penetration.
- We Placed the prepared sample at room temperature (15°C - 30°C) for one hour.
- Placed the container below the needle of penetrometer and gradually lower the needle to make a contact with the bitumen. Ensure that the needle is just in contact with the sample and no penetration is affected. Place a lamp on one side of the needle in such a way that it creates a sharp shadow of needle on the sample. This will help in correct positioning of the needle.
- Pressed the push button of the control box to release the needle. The needle will penetrate the sample under its own weight for 5 seconds and after that it will stop automatically. Note down the reading.
- We took three readings for each test of our sample and noted down the readings

for conclusion of the results from the experiments.

OBSERVATIONS:

- Pouring temperature = 25°C
- Period of cooling in room temperature = 1 hour
- Room temperature = 25°C
- Water bath temperature = 25^o C

PRECAUTIONS:

- Overheating of bitumen should be avoided.
- Under no condition bitumen should be heated to 60^o C above the expected softening point.
- The sample is covered loosely against dust
- The weight of needle and spindle assembly should be accurate i.e., 100 ± 0.05 grams.
- Verticality of the needle should be ensured.
- Readings taken on a single sample should be at least 10 mm apart.

GRADE SPECIFICATIONS:

Bitumen Grade	***Penetration Value***
S-35	30 to 40
S-45	40 to 50
S-55	50 to 60
S-65	60 to 70
S-90	80 to 100
S-200	175 to 225

1. 3.2.4 SOFTENING POINT OF BITUMEN

2. (AASHTO T 53-89 & ASTM D 36 – 95,)

This test method covers the determination of the softening point of bitumen in the range from 30 to 157°C (86 to 315°F) using the ring-and-ball apparatus immersed in distilled water (30 to 80°C), USP glycerine (above 80 to 157°C), or ethylene glycol (30 to 110°C). Softening point is a consistency test and consists of heating of bituminous material until they reach at the given consistency. The softening point is the temperature at which the substance attains degree of softening under specified conditions of test.

APPARATUS:

- Rings
- Pouring plates
- Balls
- Ball-centering guides
- Water Bath
- Ring Holder
- Assembly
- Thermometer

PROCEDURE:

- We heated the bitumen until it comes to liquid form.
- We filled the rings with bitumen and bring it at room temperature.
- Then assembled the apparatus with ring thermometer and balls guide in a position and filled the bath to a depth of 4 to 4.25in.
- After that We maintained the bath at a temperature of 4±1ºC for 15 minutes.
- Placed the balls on the surface of the specimen
- After that we Started the bath heater at a rate of 5ºC/ min and keep stirring as necessary.
- Then Recorded the temperature when the balls pass in the rings and touch the bottom; this is the softening point in centigrade.
- The softening point to be reported as the mean of the temperatures at

which the two discs soften enough to allow each ball, enveloped in bitumen, to fall a distance of 25mm.

- We performed these tests for each percentage and take an average of 3 samples and checked the results and analyzed and compared these results with the parent Bitumen.

PRECAUTIONS:

- Use hand gloves, apron while removing containers from hot plate after switching off the hotplate.
- Use glycerin to remove bitumen from the container.
- Use distilled water in the test for an accurate result.
- Use safety shoes & Apron at the time of the test.
- Equipment should be cleaned thoroughly before testing & after testing.

Chapter 4

4.1.RESULTS AND DATA ANALYSIS

Transportational investigations for bitumen samples were conducted to evaluate the physical parameters of bitumen and find various effects in waste polymer-modified bitumen. The scope of our laboratory evaluation incorporates softening point tests, penetration tests, ductility tests, viscosity tests, and storage stability tests. Our project's main aim is to overcome the

BITUMEN WITH 0% CRUMB RUBBER					
TESTS	**S1/R1**	**S2/R2**	**S3/R3**	**S4/R4**	**S5/R5**
Softening C°	54.6	55.8	56		
Penetration (mm)	61.6	76.1	78		
Ductility (mm)	600	580	610		

Table:1 "Data of physical tests at 0% polymer modified bitumen"

incompatibility between bitumen and polymer, which is waste crumb rubber. To overcome the

incompatibility, we will add titanium dioxide to the polymer-modified bitumen and then compare the results. First, we found the physical parameters of our bitumen sample with 0% crumb rubber and the results we obtained were:

By doing the physical tests we confirmed that our bitumen sample was of 60/70 grade. After that we added the waste polymer (crumb rubber) in the bitumen at 5%, 10% and 15% by weight of bitumen. The test results at 5% of crumb rubber were:

BITUMEN WITH 5% CRUMB RUBBER					
TESTS	**S1/R1**	**S2/R2**	**S3/R3**	**S4/R4**	**S5/R5**
Softening	61.6	58.6	61		
Penetration (mm)	69.6	61.9	58.9		
Ductility (mm)	227	230	240		

Table:2 "Data of physical tests at 5% polymer modified bitumen"

We noticed that at 5% of crumb rubber, the softening point of bitumen increased. While on the other side, penetration and ductility decreased. The test results at 10% of crumb rubber were:

BITUMEN WITH 10% CRUMB RUBBER					
TESTS	**S1/R1**	**S2/R2**	**S3/R3**	**S4/R4**	**S5/R5**
Softening	58.1	59.1	61.2		
Penetration	30.9	34.1	33.3	30.3	31.8
Ductility	114	164			

Table:3 “Data of physical tests at 10% polymer modified bitumen”

At 10% crumb rubber, the softening point of bitumen was almost same to that of 5%, but penetration and ductility were still decreasing. Next we added 15% crumb rubber in bitumen, the softening point of modified bitumen increased and penetration decreased and the test results were:

BITUMEN WITH 15% CRUMB RUBBER					
Tests	**S1/R1**	**S2/R2**	**S3/R3**	**S4/R4**	**S5/R5**
Softening test	62.5	64.2	64		
Penetration	23.5	29.1	25.3	29.1	28.7
Ductility					
Viscosity					

Table:4 “Data of physical tests at 15% polymer modified bitumen”

After conducting these tests, we added Titanium dioxide (TiO_2) at 4%, 8% and 12% by weight of bitumen one by one in modified bitumen samples. At 5% crumb rubber firstly, we added 4% Titanium dioxide (TiO_2) which gave us following results:

Bitumen with 4% TiO_2					
Tests	**S1/R1**	**S2/R2**	**S3/R3**	**S4/R4**	**S5/R5**
Softening test	59	60.2	61.5		
Penetration	25.3	22.7	23.2		
Ductility	80	95	105		

Table:5 “Data of physical tests at 5% PMB with 4% TiO_2”

We noted that when we added 45 crumb rubber in the bitumen the softening point remained almost same but the penetration and ductility decreased. After this we added 8% Titanium dioxide (TiO_2) in the 5% polymer modified bitumen which increased the softening point of 5% modified bitumen and further decreased the penetration and ductility. The results were:

Bitumen with 8% TiO2					
Tests	**S1/R1**	**S2/R2**	**S3/R3**	**S4/R4**	**S5/R5**
Softening	60.4	62.1	63.8		
Penetration	27.6	20	23.8		
Ductility	85	107	95		

Table:6 "Data of physical tests at 5% PMB with 8% TiO_2"

Then we added 12% of Titanium dioxide (TiO_2) in the 5% polymer modified bitumen which told us that the softening point of bitumen remained same yet increasing the penetration and ductility, giving us following results:

Bitumen with 12% TiO2					
Tests	**S1/R1**	**S2/R2**	**S3/R3**	**S4/R4**	**S5/R5**
Softening	60.9	65.3	60.1		
Penetration	37.2	34.5	31.7		
Ductility	97	125			

Table:7 "Data of physical tests at 5% PMB with 12% TiO_2"

Now we will add the same percentages of Titanium dioxide (TiO_2) in the 10% polymer modified bitumen which gave us following results:

Bitumen with 4% TiO2					
Tests	**S1/R1**	**S2/R2**	**S3/R3**	**S4/R4**	**S5/R5**
Softening	48.2	51.3	50		
Penetration	18.2	19.6	22.1		
Ductility	98	102	109		

Table:8 "Data of physical tests at 10% PMB with 4% TiO_2"

Bitumen with 8% TiO2					
Tests	**S1/R1**	**S2/R2**	**S3/R3**	**S4/R4**	**S5/R5**
Softening	55.9	56.9	57		
Penetration	20.4	24.7	19.5		
Ductility	114	111	146		

Table:9 "Data of physical tests at 10% PMB with 12% TiO_2"

The results for the 10% Polymer modified bitumen with 12% Titanium dioxide (TiO_2) are not obtained yet. After that, we will add same percentages of Titanium dioxide (TiO_2) in the 15% polymer modified bitumen. In the end we will perform the viscosity test on all these samples and for overcoming the incompatibility we will conduct storage stability test on all the polymer modified bitumen samples having titanium dioxide (TiO_2).

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CONTRUBUTION:

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