

Investigating Hybrid Waste-Modified Bituminous Mixes Experimentally for Improved Performance and Durability

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Abstract - In today's world, where cities are growing quickly and infrastructure is expanding, road networks are very important for connecting cities, suburbs, and rural areas. This helps the economy grow and people move around. But the rising costs of traditional road building materials and growing environmental concerns have become big problems for the pavement industry. To solve these problems, we need to use more sustainable and cost-effective materials that don't hurt the structural performance or service life of pavements.

India has one of the largest road networks in the world, but it also has a lot of problems with managing the rapidly growing amount of solid waste, such as plastic waste, old tires, and used oils. The use of waste materials in bituminous mixes has become very popular in recent years as a way to be more environmentally friendly and follow the rules of a circular economy.

Prior research has shown that waste materials, including polyethylene (LDPE, HDPE), polyethylene terephthalate (PET), crumb rubber, industrial by-products, and waste engine oil, can be effectively employed as modifiers in bituminous mixtures. Adding these materials has been shown to improve important performance factors for flexible pavements, such as Marshall Stability, resistance to rutting, moisture susceptibility, and overall durability. Research also shows that a controlled amount of waste materials (up to about 25–30%) can be used without harming the mix's engineering properties.

In the current sustainability-driven environment, especially in developing areas and rural infrastructure projects, using waste-modified bituminous mixes has many benefits, such as lower costs, better pavement performance, less waste going to landfills, and a smaller carbon footprint. So, using waste materials to build flexible pavement is a promising and environmentally friendly way to build transport infrastructure in the future.

Keywords: Flexible pavement, Waste Plastic, Crumb Rubber Modified Bitumen (CRMB), Waste Engine Oil, Sustainable Road Construction.

1. Introduction

The present state of affairs shows that people keep increasing their numbers while they use plastic polymers and cars which lead to intensified pollution problems from waste polymer accumulation. The public faces multiple challenges in their daily activities because waste polymers require decomposition. The existing waste materials need immediate disposal because their non-decomposition will cause them to remain in nature for centuries which will worsen environmental pollution. The materials can be effectively decomposed through recycling or repurposing waste into useful applications. Scientists have developed new ways to handle waste materials through their recent research work. Private companies and highway agencies have successfully completed research projects that established sustainable methods for using waste polymers in road construction work to enhance project performance. The studies focus on two main objectives, which include establishing secure waste disposal methods that will create economic value and developing cost-effective road construction solutions. The research shows that waste materials can replace conventional construction materials in most applications. The research focuses on developing new waste material management solutions through its work on innovative waste material recycling technologies.

2. Literature Review

Vashisht and Saini (2017) utilized waste plastic and CRMB in the flexible pavement. In this study, the wet and dry process was adopted for preparing the modified bitumen. Samples were prepared according to the ministry of road transport and highway (MORT&H) specification. In the wet process, first bitumen was heated at the temperature of 160°C and temperature was recorded at the time of softening of material. Later, waste material was added in the mix for avoiding agglomeration in the material. In this % of modified agent vary from 1% to 16 %. In the dry process, it was only done with plastic waste by cutting it into small size of around 3mm-6mm and mixed with the aggregate at the temperature of 165°C. On the other hand, bitumen was heated at a temperature of 160°C for having good binding strength. After that sample was

made with 8% of plastic waste and 16% of plastic waste. In the present study, CRMB was not utilized in order to make the sample because of the poor bonding quality (i.e. b/w CRMB and aggregates).

As per the result, impact value was found to be increased up to 10% due to the addition of plastic waste (i.e. worked as a coating material for aggregate). The specific gravity of plain and modified aggregates was found to be same while penetration value and ductility value of modified bitumen was lower than the conventional one.

Kawade et al. (2018) investigated a study on design and qualitative analysis of flexible pavement containing waste materials. The waste materials utilized in this study as the replacement of natural aggregates were namely crushed stone, steel slag, recycled concrete and CRMB (by cutting waste rubber tires in pieces that could pass through 2.36 mm sieve and were retained on 1.18 mm sieve. Marshall Stability test was performed for each type of mixes containing different waste material as the replacement of aggregates and VG-30 bitumen mix. In the case of steel slag, the impact value and crushing value was found to be around 9.33% and 15.42% respectively which is appropriate for highways construction as per to Indian road congress (IRC). While impact value and crushing value of recycled concrete aggregate was 24.69% and 31.47% respectively which are not as per the IRC's specifications? Marshall Stability and the flow value of mix containing steel slag were found to be 990.6kg and 2.1mm respectively, which satisfies the IRC's guidelines.

Sharma et al. (2018) examined the performance of bituminous paving mix containing waste plastic. The material used was crushed basalt type of course aggregate 20 mm, crushed basalt type of fine aggregate 2.36 and down, 80/100 penetration grade bitumen, basalt stone dust, and cement as a mineral filler. While the waste plastics namely polyethylene terephthalate (PET), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), low-density polyethylene (LDPE), high-density polyethylene (HDPE) was used in the shredded form. Marshall Stability test was carried out with varying % of plastic waste in order to check the stability of the mix. Later, a comparison b/w the results of BC (Bituminous concrete) mix with waste plastic and plain BC mix was made. Consequently, the stability value of optimum plastic content OPC (optimum plastic content) was found to be 30.1, which was much higher than the optimum bitumen content OBC (optimum bitumen content). The volume of voids in BC mix containing plastic waste was found lower than the plain BC mix. These results were within the parameters of MORT&H-2001 specifications.

The test concluded that the OPC mix showed higher stability as compared to OBC mix and intermolecular binding b/w bitumen and waste plastic enhances the strength, durability, and life of roads.

Sarma and Srikanth (2018) utilised waste polythene in the bituminous paving mix design. The materials used in the study were bitumen, aggregate and waste plastic. Marshall Stability test was performed and carried out in two parts to determine optimum bitumen content (OBC) and optimum plastic content (OPC). Different samples were made with different ratio of bitumen, aggregates, and plastic. After that test was conducted at the temperature of 60°C to check the OBC which was found to be 5.8%. Later, disposed milk packets were used to determine OPC. The specific gravity and softening point were taken from the report of milk packets manufacturer and report specified the specific gravity and softening point value around 0.92 and 115°C respectively. So according to the result, the value for plastic content corresponding to maximum stability was equal to 10%. The value of binder content corresponding to maximum bulk specific gravity was found to be equal to 7.5%. Average of the above values came out to be 8.75%.

The results from the test stated that, the OBC was 5.8% and the OPC was concluded to be 8.75%. Thus, it was concluded that addition of plastic waste material content in bitumen increases the stability as comparison to conventional bituminous mix.

Anand & Raju (2024) conducted a study on the utilization of waste plastic in bituminous concrete mix for road construction. They examined the mechanical properties of bituminous mix modified with two different plastic wastes (thickness more than 40 microns and less than 40 microns) using the dry process. The study evaluated parameters such as Marshall Stability, Flow, Indirect Tensile Strength (ITS), and Retained Stability. Their findings revealed that waste plastic-modified bituminous mixes performed better than conventional mixes, exhibiting improved abrasion value, crushing strength, impact value, and water absorption resistance. The research also emphasized the economic and environmental benefits of utilizing locally available aggregates and reducing plastic waste through road construction. The study concluded that replacing base bitumen with waste plastic is both economical and environmentally friendly.

Garg & Duggal (2024) investigated the use of waste plastic in bituminous mixes to enhance pavement durability and resistance to moisture damage. The study highlights that while waste plastic improves anti-stripping properties; its widespread adoption faces challenges such as financial constraints, technological limitations in hot mix plants, and inconsistent supply of high-quality waste plastic. They identified key obstacles, including high initial costs, lack of

awareness, and difficulties in integrating plastic into current production processes. The authors emphasized that overcoming these barriers requires supportive regulations, technological advancements, and improved supply chain mechanisms to facilitate broader use of waste plastic in road construction.

Chaturvedi et al. (2025) conducted a laboratory investigation on the modification of bituminous mix design using plastic waste and crumb rubber. The study aimed to evaluate the mechanical properties of Stone Mastic Asphalt (SMA) mixes by incorporating plastic waste (PET bottles) and crumb rubber as modifiers. The experimental analysis included Marshall Stability, flow value, voids in mineral aggregates (VMA), and indirect tensile strength (ITS). The results indicated that the optimum plastic waste content was 6.3%, which provided higher stability, improved fatigue life, and enhanced rutting resistance compared to conventional bituminous mixes. The study concluded that modifying SMA with plastic waste and rubber can enhance pavement durability while promoting sustainable road construction practices.

2.1 Research Objectives

- ❖ The process reduces bitumen consumption through partial replacement with waste materials such as waste LDPE and HDPE and CRMB and motor oil and steel slag.
- ❖ The pavement construction process uses waste material to build environmentally sustainable structures which achieve cost savings while maintaining essential construction requirements.
- ❖ The process decreases greenhouse gas emissions while it helps to preserve available space in landfills.

3. Methodology

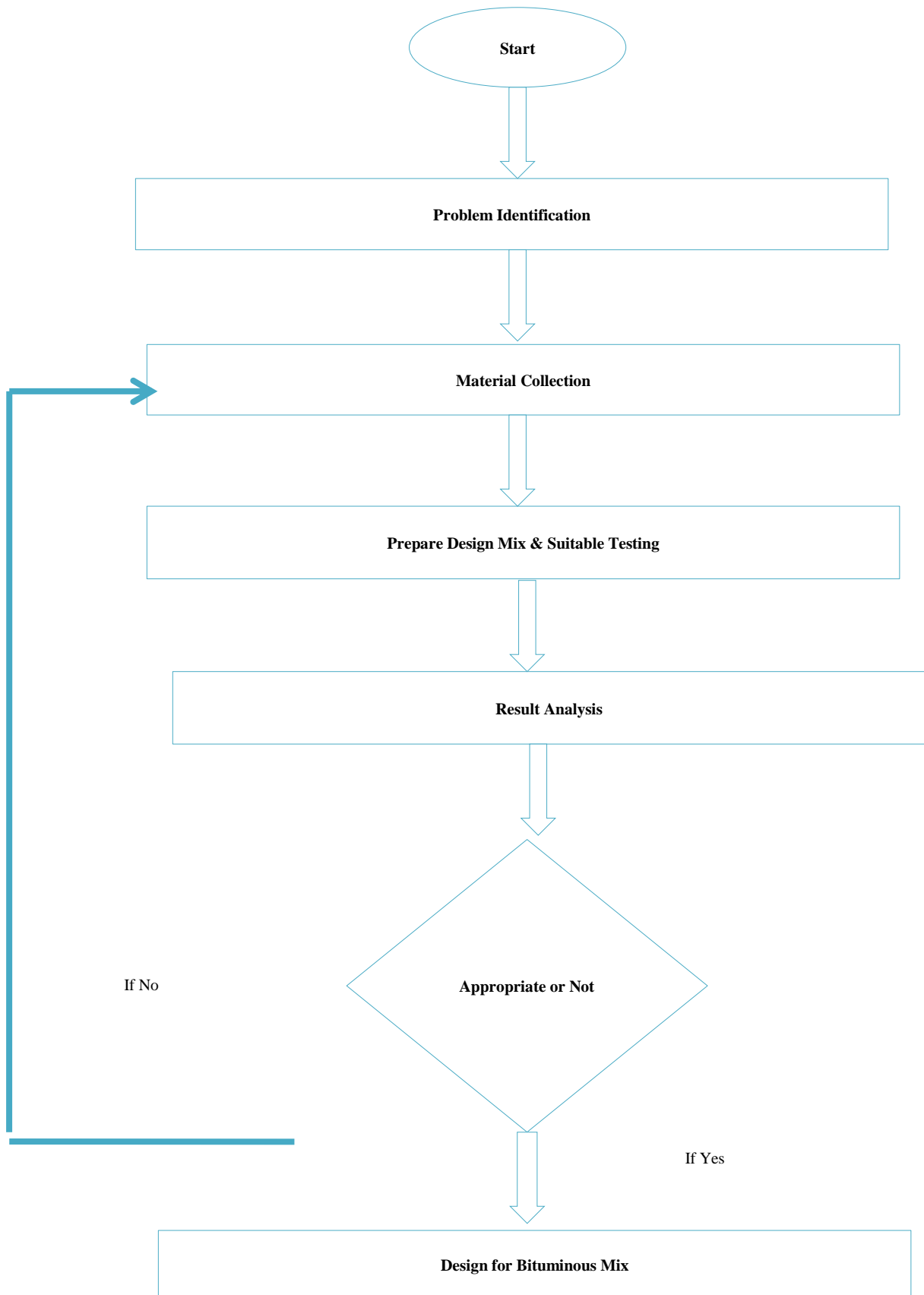


Figure 3.1:- Methodology Flow Chart

3.1 Selection of Material

The study used VG10 and 80/100 penetration grade bitumen together with multiple waste materials for testing purposes. The research team created different samples which contained different material combinations. The researchers chose waste materials according to their chemical properties which the next subsection of this chapter describes in detail.

Table 3.1 Chemical Composition of Bitumen (Raha Bitumen Co.)

Chemical Elements	Elements Range	Unit
Carbon	80.2-84.3	%
Nitrogen	0.2-1.2	%
Hydrogen	9.7-10.7	%
Sulphur	0.8-6.8	%
Oxygen	0.5-1.1	%
Nickel	11-137	Ppm
Vanadium	8-1595	Ppm
Iron	6-149	Ppm
Manganese	0.1-3.8	Ppm
Calcium	1-335	Ppm
Magnesium	1-134	Ppm
Sodium	6-157	ppm

Table 3.2 Chemical Composition of Polyethylene (CHEMIK 2013, 67, 5, 435?445)

Chemical Elements	Elements %
Carbon	81.90
Nitrogen	0.45
Hydrogen	12.38
Sulphur	1.94
Oxygen	0.0
Calcium	0.98

Table 3.3 Chemical Composition of Waste Engine Oil (Ikhajiagbe, et.al P.,2024)

Chemical Elements	Weight (mg/kg)
Iron	3253.65
Manganese	12.36
Zinc	54.13
Copper	33.53
Chromium	23.23
Lead	12.45
Nickel	11.84
Vanadium	8.21
Cadmium	24.85

Table 3.4 Physical Composition of CRMB (Behnia, A et.al., 2017.)

Elements	Elements %
Acetone	9.3
Ash Cement	8.5
Carbon	28.1
Rubber Hydro Carbon	50.2
Heat Loss	0.9
Metal Content	0.8
Fibre Content	1.5

Table 3.5 Chemical Composition of CRMB (Donga et.al., 2016.)

Elements	Elements %	Unit
Carbon	87.53	%
Oxygen	9.25	%
Zinc	1.75	%
Sulphur	1.07	%
Silicon	0.21	%
Manganese	0.13	%

Aluminum	0.09	%
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3.2 Waste Production in India

India produces large quantities of waste according to multiple research studies and various reports which show that many of these waste materials can be reused for building roads. The FICCI report states that India generates 3.5 million tonnes of plastic waste every year which primarily comes from household waste including plastic bags and bottles and packaging materials. The waste stream mainly consists of single-use plastics which require recycling for their decomposition. The plastic waste from these products creates major environmental pollution which harms both terrestrial and aquatic ecosystems. The development of new methods which enable their application as road construction materials has produced successful outcomes. The National Rural Road Development Agency reported that in 2016, 7,600 km of roads were built using waste plastic, demonstrating the feasibility of this method. India is among the top countries that produce waste tyres in large quantities. Lalatendu Mishra conducted research which found that worldwide about 1.5 billion tyres get produced each year while an identical number of tyres get disposed. India produces 6 to 7 percent of the global waste tyre generation according to current estimates. The recycling rate for discarded tyres remains low at 8 to 10 percent after three decades of recycling attempts while 10 to 12 percent of discarded tyres undergo incineration to produce fuel. More than 70 percent of the waste ends up in unlicensed dumping sites and landfills which create major dangers to the environment. Road construction projects benefit from using waste tyres because they solve landfill space problems while offering a green waste disposal method. Waste engine oil from vehicles combines with plastic and rubber waste to create a major environmental problem throughout the nation. The oil recycling factories in India can handle only half of the waste oil that factories generate according to their current recycling capacity. The 45 to 50 percent of oil which remains after processing gets thrown away which creates environmental damage. Researchers found that using processed waste oil together with bituminous mixtures results in better road performance and lower construction expenses. The method creates a waste oil management solution that is both sustainable and cost-effective. India can decrease landfill waste and pollution while building roads through the use of plastic and tyre and waste oil materials. India still produces substantial waste materials which can be used for road construction according to recent research and reporting.

3.3 Methods for Testing Samples or Construction of Roads

- a) Dry Process
- b) Wet Process

Dry Process: The dry process starts with the heating of aggregates to specific temperatures which leads to the application of shredded materials or waste liquids into the hot aggregate chamber. This application creates a shiny surface which protects the aggregates from bitumen application. The construction of roads uses this process as its primary method.

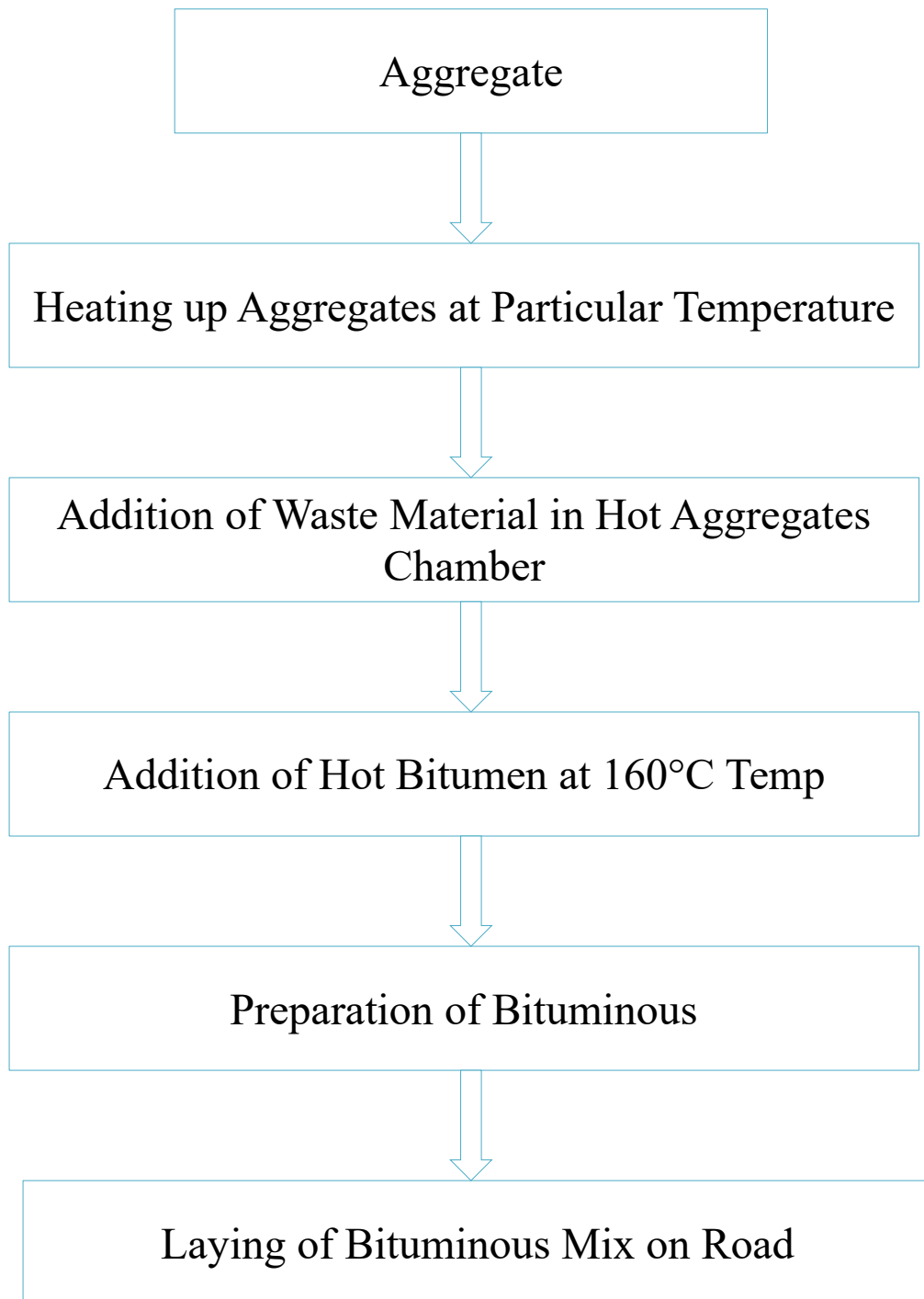


Figure 3.2:- Flow Chart of Dry Process

Wet Process: In this bitumen heating method, the hot bitumen (160°C) is kept ready and pieces of waste are blended with bitumen. The mixture thus obtained is then spread on the upper surface of the road, but for the earnest process of road work, the widely believed method is compacting with films.

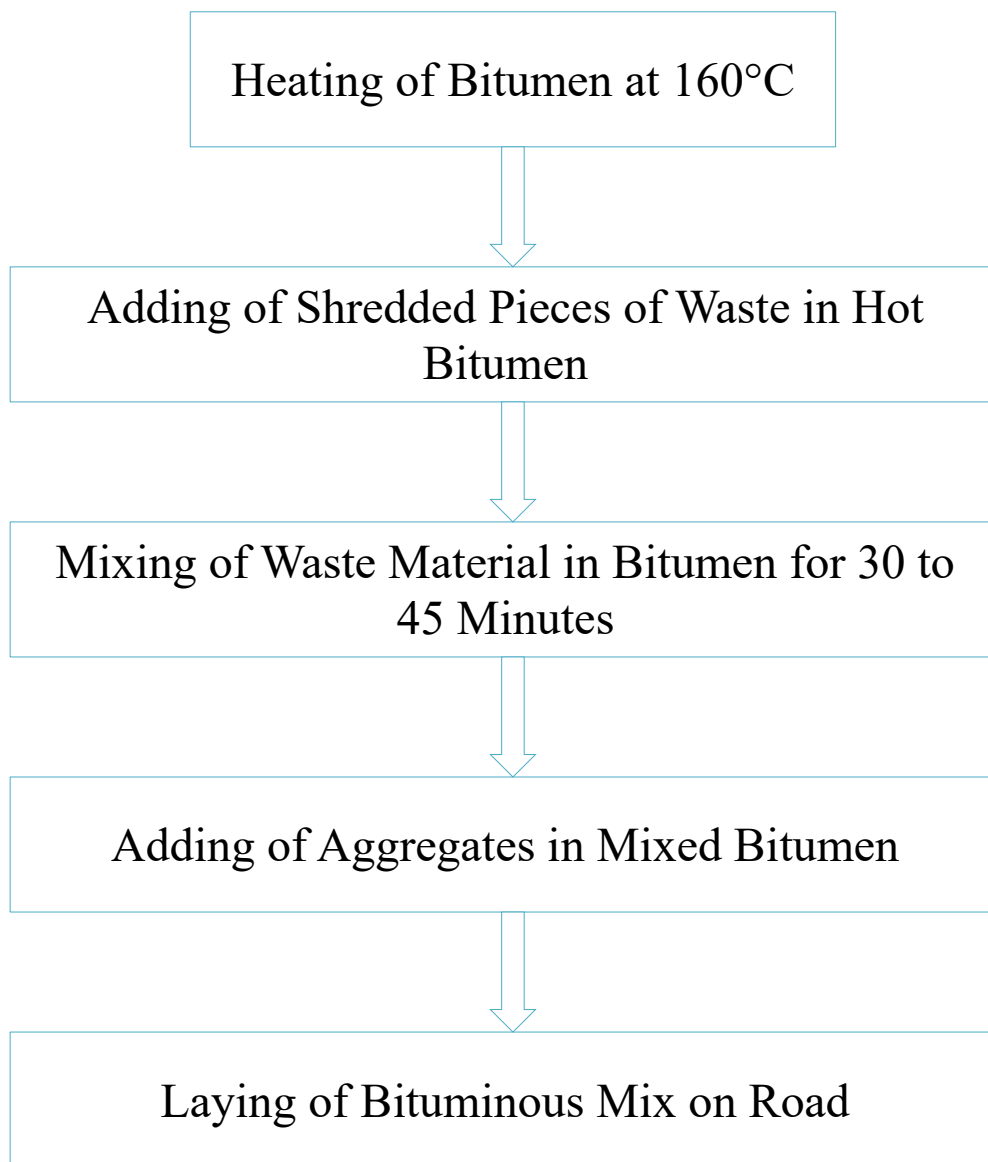


Figure 3.3:- Flow Chart of Wet Process

3.4 Test Conducted on Bitumen with Different Waste by Using Wet Process

1. **Penetration Test (IS 1203:1978):-** The penetrometer device performs bitumen penetration assessment through its testing process. The testing process needs to follow the established standards of IS 1203. The penetration test determines how soft or hard the bituminous mix material exists. Bitumen comes in different grades which each possess their particular penetration measurement. The penetration test establishes that the 80/100 penetration grade should produce results between 80 and 100. The penetration test requires specific testing parameters which include load and duration and temperature settings because the results show measurements in millimeters (mm).
2. **Ductility Test (IS 1208:1978):-** The ductility test measures the bitumen's capacity to maintain its structural integrity. The testing process evaluates how far bitumen material can stretch before breaking. Road construction needs ductility as its fundamental material property. Bitumen stretching capacity reduction leads to road cracks because it weakens the strength of bituminous materials. The sample undergoes testing under particular speed and temperature conditions which produce ductility test results shown in centimeters. The ductility test follows the testing standards established by IS 1208

3. **Softening Point Test (IS 1205:1978)**- The softening point test determines the temperature at which bitumen material becomes soft. The process requires full compliance with IS 1205 standards. The softening point test uses the ring and ball apparatus to conduct its assessment. The sample reaches its softening point when it fails to support the ball's weight and touches the steel plate.
4. **Specific Gravity Test (IS 1202:1978)** - The specific gravity test of bitumen measures the specific gravity which compares the mass of bituminous material at specific volume with specific temperature to water volume at the same temperature. The process requires implementation through density bottle usage according to IS 1202 standards.

3.5 Material Used for Sample Preparation

The created samples included engine oil at concentrations of 0%, 2%, 4%, 6%, 8% and 10% CRMB powder at 0%, 2%, 5%, 8% and 10% concentrations and LDPE waste at 0%, 2%, 5%, 7% and 9% concentrations. The testing used VG 10 and 80/100 bitumen grade together with HDPE waste and samples that contained 2% LDPE combined with 3% HDPE and 4% engine oil and 3% HDPE combined with 4% engine oil and 5% CRMB powder and 4% engine oil combined with 5% CRMB powder and 2% LDPE and 5% CRMB powder combined with 2% LDPE and 3% HDPE.



Figure 3.4:-Shredded Pieces of Waste LDPE

3.6 Sample Preparation

The researchers conducted multiple experiments through the application of a wet method. The scientists used a hot plate to raise bitumen temperature until it reached its melting point. The material was heated on the induction plate until it reached a temperature of 160°C which took several minutes to achieve. The boiling point of bitumen was reached so the team introduced shredded waste material and stirred for thirty minutes. The researchers used bitumen to create a separate mold after completing all mixing processes for their testing purposes. The mold underwent a cooling process for thirty minutes before the researchers transferred it to a water bath chamber which maintained a temperature of 25°C for one hour. The researchers conducted multiple tests on the sample after one hour which included testing for bitumen penetration and specific gravity and softening point and ductility.

4. Result Analysis

4.1 Testing of Bitumen with Waste LDPE

Penetration Test Result of Bituminous Mix with Waste LDPE

Penetration test carried out by following proper guideline of IS code IS 1203 with different sample of bitumen with 0%, 3%, 6%, and 9% LDPE.

Table 4.1 Penetration Test Result of Bitumen with Waste LDPE

Samples with Different Compositions	Test Result
0%	80
3%	45
6%	60
9%	85
12%	70



Figure 4.1:-Penetrometer



Figure 4.2:-Sample for Penetration Test

4.2 Testing of Bitumen with Mixed Composition of Waste HDPE, LDPE, Engine Oil and CRMB Powder

4.2.1 Penetration test result of bitumen with waste HDPE, LDPE, Engine oil and CRMB powder.

Penetration test carried out by following proper guideline of IS code IS 1203 by making different sample of bitumen by making four samples mixed composition of different waste content with VG10 bitumen. Samples were made with 2% LDPE + 3% HDPE + 4% Engine oil, 3% HDPE + 4% Engine oil + 5% CRMB powder, 4% Engine oil + 5% CRMB powder + 2% LDPE and 5% CRMB powder + 2% LDPE + 3% HDPE.

Table 4.21 Penetration Test Result of Bitumen with Waste HDPE, LDPE, Engine Oil and CRMB Powder

Sample with Different Compositions	Test Result
0%	80
2 % LDPE + 3 % HDPE + 4% Engine Oil	80
3 % HDPE + 4% Engine Oil + 5 % CRMB Powder	89
4% Engine Oil + 5 % CRMB Powder + 2 % LDPE	85
5 % CRMB Powder + 2 % LDPE + 3 % HDPE	82

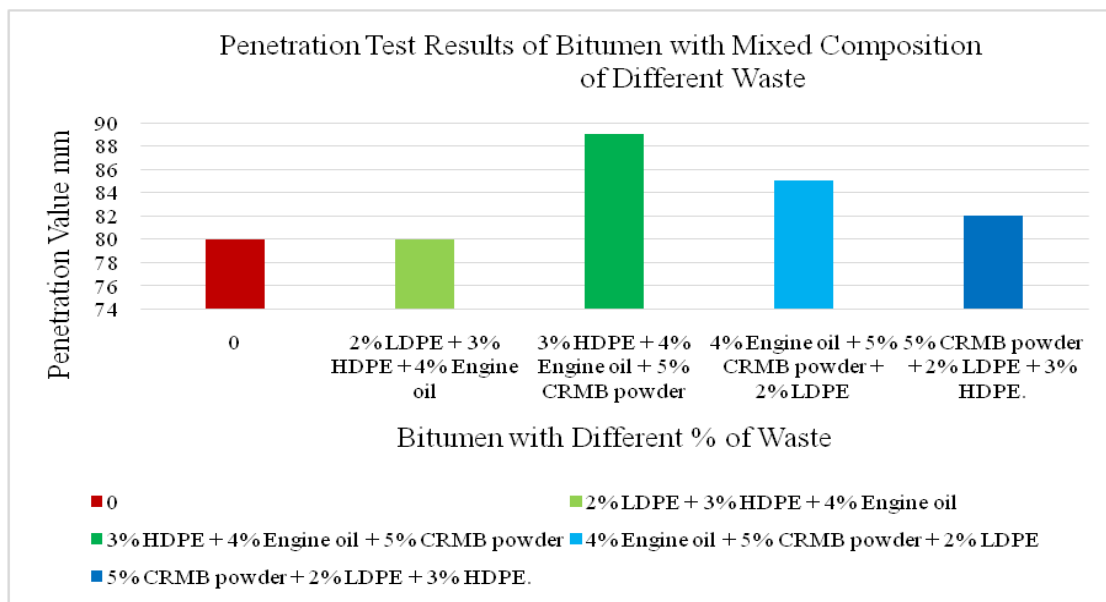


Figure 4.25:- Penetration Test Results Graph of Bitumen with Mixed Composition of Different Waste

The Penetration test which was conducted by using penetrometer shows that, samples having 3% HDPE + 4% Engine oil + 5% CRMB powder is having maximum penetration value.

4.6.2 Softening Point Test Result of Bitumen with Waste HDPE, LDPE, Engine Oil and CRMB Powder

Softening point test was conducted with different samples with mixed composition of different waste content with VG10 bitumen. Samples were made with 2% LDPE + 3% HDPE + 4% Engine oil, 3% HDPE + 4% Engine oil + 5% CRMB powder, 4% Engine oil + 5% CRMB powder + 2% LDPE and 5% CRMB powder + 2% LDPE + 3% HDPE

Table 4.22 Softening Point Test Result of Bitumen with Waste HDPE, LDPE, Engine Oil and CRMB Powder.

Sample with Different Compositions	Test Result
0%	46 ^o C
2 % LDPE + 3 % HDPE + 4% Engine Oil	47 ^o C
3 % HDPE + 4% Engine Oil + 5 % CRMB Powder	42 ^o C
4% Engine Oil + 5 % CRMB Powder + 2 % LDPE	45 ^o C
5 % CRMB Powder + 2 % LDPE + 3 % HDPE	48 ^o C

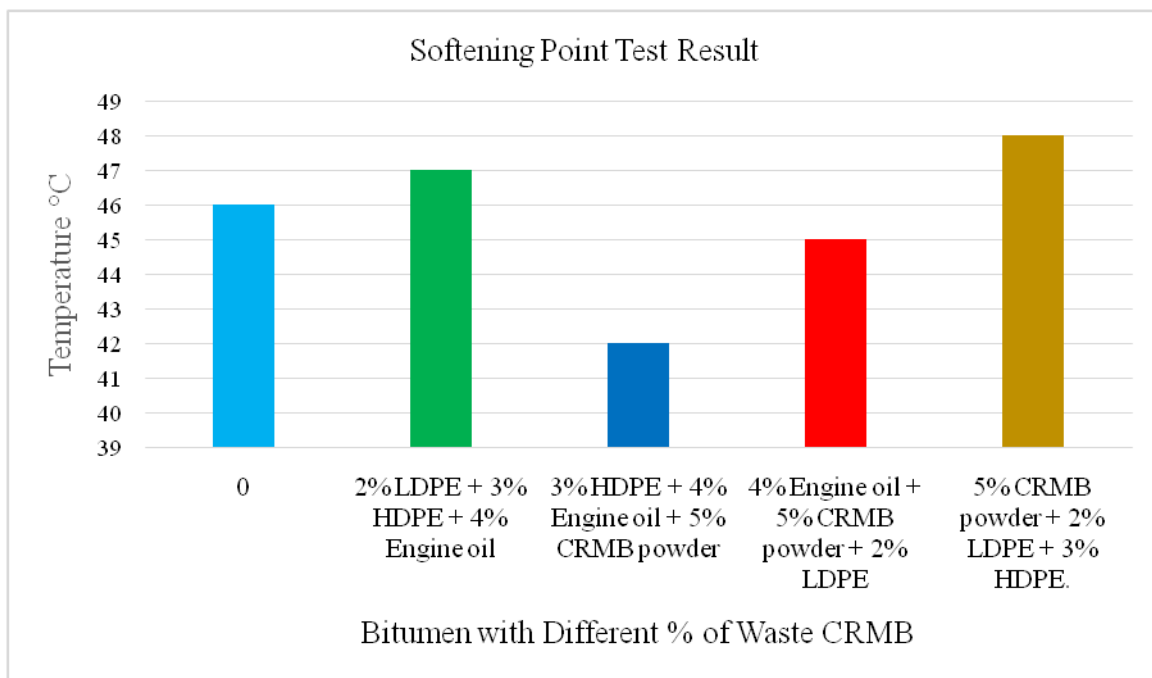


Figure:-4.26 Softening Point Test Result Graph

In softening point test result, the test was conducted with four different sample made with different composition and On the basis of result, sample having 5% CRMB powder + 2% LDPE + 3% HDPE shoes maximum softening point value.

4.6.3 Ductility Test Result of Bitumen with Waste HDPE, LDPE, Engine Oil and CRMB Powder

Ductility test was done with proper guideline of IS 1208, by making different samples with mixed composition of different waste content with VG10 bitumen. Samples were made with 2% LDPE + 3% HDPE + 4% Engine oil, 3% HDPE + 4% Engine oil + 5% CRMB powder, 4% Engine oil + 5% CRMB powder + 2% LDPE and 5% CRMB powder + 2% LDPE + 3% HDPE.

Table 4.23 Ductility Test Result of Bitumen with Waste HDPE, LDPE, Engine Oil and CRMB Powder

Sample with Different Compositions	Test Result
0%	75 cm
2 % LDPE + 3 % HDPE + 4% Engine Oil	72 cm
3 % HDPE + 4% Engine Oil + 5 % CRMB Powder	87 cm
4% Engine Oil + 5 % CRMB Powder + 2 % LDPE	82 cm
5 % CRMB Powder + 2 % LDPE + 3 % HDPE	79 cm

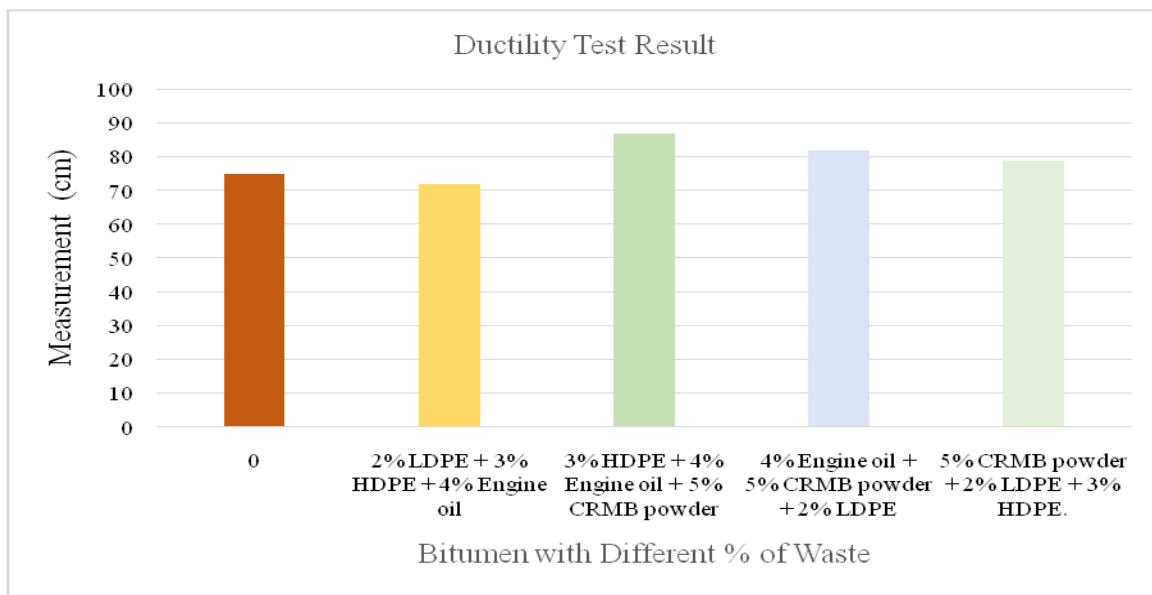


Figure 4.27:- Ductility Test Graph of Bitumen with Mixed Composition

In ductility test result, the test was conducted with four different sample made with different composition and On the basis of result, sample having 3% HDPE + 4% Engine oil + 5% CRMB powder shoes maximum ductility value.

4.6.4 Specific Gravity Test Result of Bitumen with Waste HDPE, LDPE, Engine Oil and CRMB Powder.

Specific gravity test result was conducted by two different specific gravity bottles of different size for different samples with mixed composition of different waste content with VG10 bitumen. Samples were made with 2% LDPE + 3% HDPE + 4% Engine oil, 3% HDPE + 4% Engine oil + 5% CRMB powder, 4% Engine oil + 5% CRMB powder + 2% LDPE and 5% CRMB powder + 2% LDPE + 3% HDPE.

Table 4.24 Specific Gravity Test Result of Bitumen with Waste HDPE, LDPE, Engine Oil and CRMB Powder

Sample with Engine Oil Waste	Weight of Empty Bottle	Weight of Bottle with distilled Water	Weight of Bottle with Half-distilled Bitumen	Weight of Bottle with Bitumen and distilled water	Specific Gravity Calculation
0%	55 gm	114 gm	80 gm	115 gm	1.03
2 % LDPE + 3 % HDPE + 4% Engine Oil	48 gm	98 gm	59 gm	99 gm	1.1
3 % HDPE + 4% Engine Oil + 5 % CRMB Powder	31 gm	85 gm	64 gm	89 gm	1.06
4% Engine Oil + 5 % CRMB Powder + 2 % LDPE	43 gm	94 gm	77 gm	95 gm	1.03
5 % CRMB Powder + 2 % LDPE + 3 %	57 gm	112 gm	83 gm	111 gm	0.96

HDPE					
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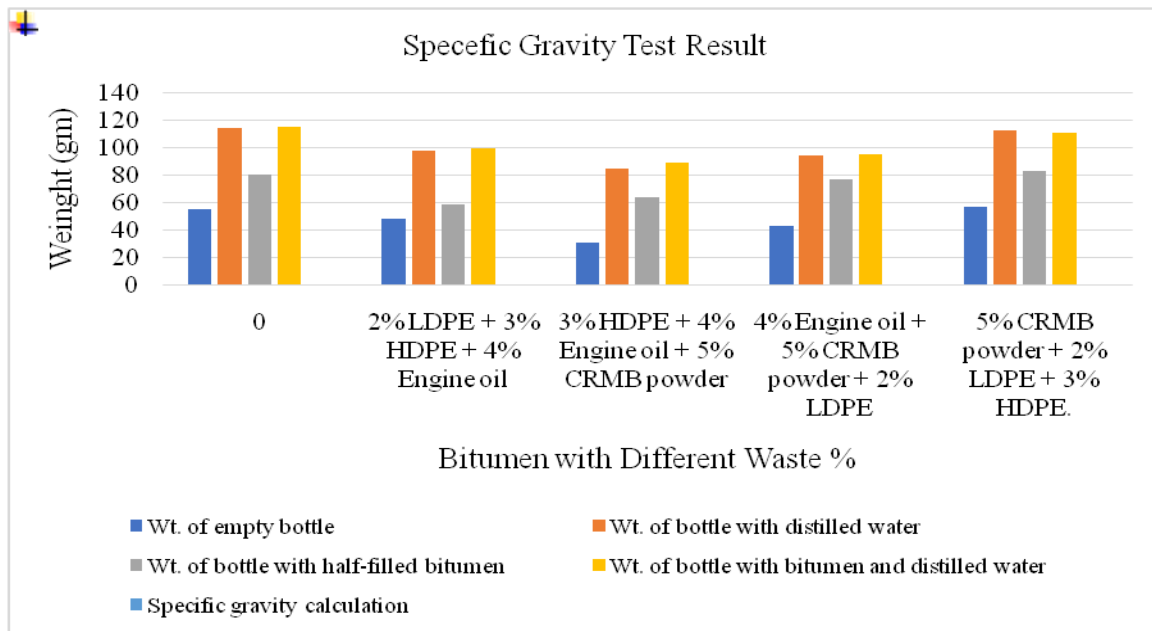


Figure 4.28:- Specific Gravity Test Graph of Bitumen with Mixed Composition

In specific gravity test, test was conducted with different size of bottles and different samples of modified bitumen and result of all samples were almost same.

4.6.5 Marshall Stability Test Result of Bitumen with Waste HDPE, LDPE, Engine Oil and CRMB Powder.

Marshall Stability test result was conducted by making sample of bitumen with different samples with mixed composition of different waste content with VG10 bitumen. Samples were made with 2% LDPE + 3% HDPE + 4% Engine oil, 3% HDPE + 4% Engine oil + 5% CRMB powder, 4% Engine oil + 5% CRMB powder + 2% LDPE and 5% CRMB powder + 2% LDPE + 3% HDPE.

Table 4.25 Marshall Stability Test Result of Bitumen with Waste HDPE, LDPE, Engine Oil and CRMB Powder

Bitumen Content in %	Stability of Convention al mix 0% (KN)	Stability of mix having 2 % LDPE + 3 % HDPE + 4% Engine Oil	Stability of mix having 3 % HDPE + 4% Engine Oil + 5 % CRMB Powder	Stability of mix having 4% Engine Oil + 5 % CRMB Powder + 2 % LDPE	Stability of mix having 5 % CRMB Powder + 2 % LDPE + 3 % HDPE
3	5.4	5.9	6.3	6.7	6.5
4	7.1	7.3	7.1	7.5	6.9
5	6.2	6.4	6.7	6.5	7.1

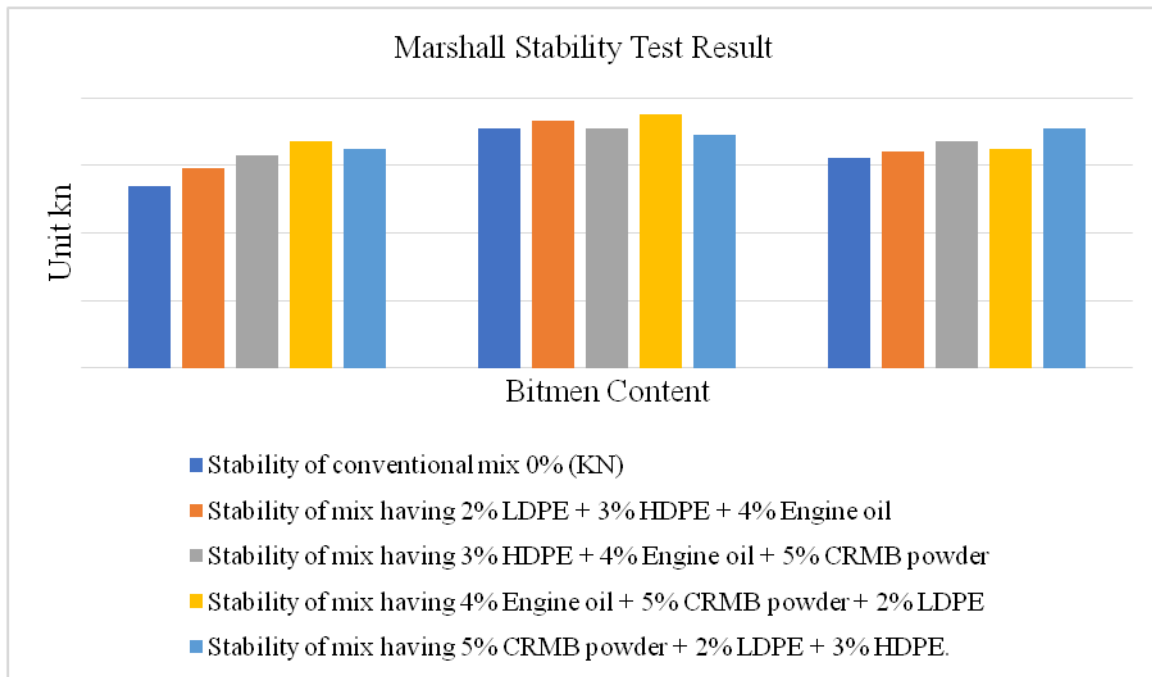


Fig. 4.29 Marshall Stability Test Result Graph of Mixed Composition with Bitumen

Marshall stability test was conducted with four different sample of mixed composition and according to the result, sample having Stability of mix having 4% Engine oil + 5% CRMB powder + 2% LDPE waste is showing maximum stability value.

5 Discussion and Conclusion

5.1 General

The research investigated various waste materials which included LDPE and HDPE as well as CRMB powder and waste engine oil which were used to replace bitumen through different ratios based on the details provided in Chapter 3. The researchers created a set of samples which used VG10 grade or 80/100 grade bitumen together with different proportions of waste additives. The researchers selected waste materials based on their chemical properties which matched the requirements of Indian Standard specifications. The study examined the effects of different waste material combinations which included LDPE at 0%, 3%, 6%, and 9% and waste engine oil at 0%, 2%, 4%, 6%, 8%, and 10% and CRMB powder at 0%, 2%, 5%, 8%, and 10% and HDPE at 0%, 2%, 5%, 7%, and 9%. The researchers produced composite mixtures by combining materials which included 2% LDPE plus 3% HDPE plus 4% engine oil and 3% HDPE plus 4% engine oil plus 5% CRMB powder and 4% engine oil plus 5% CRMB powder plus 2% LDPE and 5% CRMB powder plus 2% LDPE plus 3% HDPE which were all mixed with VG10 or 80/100 grade bitumen.

5.2 Discussion and Conclusion

The research employed several waste materials for bitumen modification which included LDPE, HDPE, CRMB powder, and waste engine oil. The study found that LDPE addition decreased penetration value until LDPE content reached a certain point which caused penetration value to increase. The softening point test showed that increasing LDPE content resulted in lower softening point values for modified bitumen. The ductility showed an initial decline before it increased again when LDPE content increased in comparison to the standard mix. All LDPE-modified samples displayed consistent specific gravity measurements that remained unchanged throughout the testing process. The penetration value for waste engine oil samples showed an initial decrease which turned into an increase at higher content levels with 8% as the maximum effective range. The ductility and softening point test results showed that the best performance occurred with 6% engine oil content which indicates this ratio works well for bitumen blending.

The use of CRMB powder resulted in better penetration and ductility and softening point performance up to 8% content which shows that this amount represents the optimal usage level with VG10 bitumen. HDPE-modified bitumen showed decreased penetration values at 2% HDPE but subsequent content increases caused penetration values to rise until they

reached 7%. The ductility exhibited a pattern of first decreasing before it began to increase when HDPE content was increased. The softening point increased with 2% HDPE but then began to drop once additional HDPE was introduced. The composition containing 3% HDPE combined with 4% engine oil and 5% CRMB powder produced the greatest penetration measurement among all waste material mixtures. The sample containing 5% CRMB powder combined with 2% LDPE and 3% HDPE achieved the highest softening point measurement. The mixture containing 3% HDPE and 4% engine oil and 5% CRMB powder showed better ductility performance than all other tested mixtures. The specific gravity measurements showed no significant variations throughout all tested material combinations.

5.3 Future Scope

The present study can be expanded through research by using higher percentages of waste materials to replace bitumen through their individual applications and their combined use. The research team will introduce more suitable waste materials based on their physical and chemical analyses. Future research will examine how different traffic flow patterns and temperature stressors impact pavement failure through their various loading effects.

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