Improving Water Resistance of Pavement using Recycled Rubber

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Abstract: - Road infrastructure is also in desperate need of a system that can improve its water resistance, since flooding frequency and intensity have increased in recent decades, resulting in infrastructure losses. Waste tire accumulation on a global scale and the ensuing environmental and social concerns are also causing concern. To address these issues, it was proposed to use recycled tire rubber crumb in combination with asphalt and aggregates to create a water-resistant pavement. This study aims to formulate a water-resistant asphalt mix. Initially, a detailed comparison study was conducted to determine the optimum asphalt content for conventional (0% rubber content) and crumb-modified mixes. The strength and retained stability of both types of mix were evaluated under soaked and unsoaked conditions based on the optimal asphalt content. To achieve this objective, recycled tire rubber crumb was mixed with asphalt and aggregate at 2%, 4% & 6% by weight of asphalt. An experimental study was conducted through Marshall Mix Design to investigate pavement water resistance. NHA general specifications were followed for aggregate gradation. The results indicate that recycled tire rubber crumb is an effective additive in asphalt mixes since it increases strength and resistance to water. The addition of recycled tire rubber crumb is recommended in asphalt mix to make pavement water resistant.

Key-Words: - Water resistance, pavement materials, modified asphalt, sustainability

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1 Introduction

A wide range of sectors rely on infrastructure for a society's economic and social well-being, including transportation, water, education, health, information and communications technologies, and agriculture. The importance of good and sustainable infrastructure can also be judged from the fact that innovative industry and infrastructure are one of the goals of the Sustainable Development Goals. Out of 17 goals, number 9 highlights the importance of sustainable infrastructure. Dependency on road networks has increased due to the reliance of daily life business activities on infrastructure. The frequency and intensity of flooding have increased in recent decades, causing infrastructure losses and damage.

Pakistan has suffered severe monsoon weather since June 2022. These rains have caused widespread flooding and landslides, with severe repercussions for human lives, property and infrastructure. According to Pakistan Monsoon Rainfall Report 2022, National rainfall as a whole in August was excessively above average (+243%) with extremely above average over Sindh (+726%), Baluchistan (+590%) & GB (+233%), above average over KP (+58%) & Punjab (+52%) and near average in AJK [1].

Worldwide enhancement in the accumulation of waste tires and associated environmental and social concerns are becoming the primary intimidations. Pakistan's estimated annual waste tire generation from 2015 to 2019, ranges from 889 to 1042 million kg [2]. For this problem, it was suggested to formulate an asphalt mix using recycled tire rubber crumb that can provide resistance against water.

The objective of this study was improving the sustainability of infrastructure against the disasters triggered by climate change by increasing the water resistivity of pavement. It was achieved through the accomplishment of the following tasks.

1. Introducing recycled tire rubber crumb as an additive to the asphalt mix, to improve the water resistivity of the asphalt concrete wearing course (ACWC).
2. Evaluating the effect of water on pavement by performing the Standard Marshal Test to determine the Stability (Resistance) value of ACWC after being exposed to water.

In this manner, this research is an effort to prove that addition of recycled tire rubber crumb in an appropriate proportion would improve the stability of the asphalt mix when exposed to rainwater and inundation. The study focused on adding recycled rubber tire crumb to asphalt mixes and determining the optimal amount of bitumen and additive (recycled rubber tire crumb) to achieve improved water resistance. The study had the limitation of relying on manual mixing for mixing asphalt, additives and aggregates.

The rest of the paper is organized in the following manner. Section 2 consists of literature review done related to the field of research. Section 3 contains the methodology of the research adopted to achieve the above-stated objectives. Section 4 encompasses the preparation, testing and detailed analysis of specimens, by following the methodology stated in section 3. Lastly, section 5 consists of the conclusion and recommendations of the project.

2 Literature Review

The primary aim of the review was to find an additive that could increase the water resistivity of pavement to improve the sustainability of the infrastructure and minimize the losses incurred by the infrastructure of Pakistan, due to disasters induced by climate change.

2.1 Climate change

Climate change is the most discussed problem of this century. It is posing a severe threat to the entire world. But the threat it poses to countries located in Africa and South Asia is highest in terms of severity. Pakistan, being in South Asia, is at severe risk. According to the Climate Risk Index 2021, Pakistan is ranked 8th most vulnerable country to climate change [3].

Pakistan is facing weather-related disasters due to climate change. The country saw the worst monsoon of its lifetime in 2022, damaging 13000 Km of roads [4].

2.2 Flooding on Pavements and Asphalt Additives

Pavement infrastructure is experiencing unanticipated climate conditions due to global warming. Extreme weather events, such as excessive precipitations, are increasing in intensity and frequency under climate change, which poses a flood risk to pavement infrastructure. The impact of flooding on pavements has become a rising concern since pavements are designed based on historical data, which do not adequately reflect current and future climate [5].

The susceptibility to water is one of the important distresses affecting the life of the flexible pavement. Various methods, including the addition of the appropriate additive, have been proposed to improve the properties of the asphalt mixture. Asphalt additives are substances that can be added to the asphalt binder to modify the properties of the final blend of Hot Mix Asphalt (HMA) [6].

2.3 Review of Different Asphalt Additives

Several studies have been conducted to evaluate the effect of asphalt additives or modifiers on pavement performance, from these studies, a few relevant research works are discussed below.

2.3.1 Latex Bitumen Binder

The presence of water in an asphalt mix can lead to premature pavement failure. To cater to this situation a solution is required through which the moisture resistivity of pavement can be increased. One way of doing this is by adding latex to the asphalt mix.

The research work was conducted in Indonesia to investigate the effect of water on asphalt concrete wearing course made using a latex-bitumen binder. Latex-bitumen was mixed with aggregate and was investigated at different latex content (0%, 2%, 4% and 6%) by weight of optimum asphalt content. The blending of mixtures was performed using a wet process and the test procedure used for the investigation was the Marshal Stability test. Six (6) Marshall Specimens were investigated; out of which three (3) were tested under Marshall Standards and the remaining three (3) were tested after immersing in a bath for 24 hours at 60 ^{o} C. To evaluate the effect of water, the Marshal index of retained stability was used. The study revealed that adding latex up to 4% increases the retained Marshall stability [7].

2.3.2 Recycled rubber

The study was conducted in China to evaluate the effect of recycled rubber on rutting and moisture susceptibility of Hot Mix Asphalt. Recycled rubber was used as an additive in three (03) different forms; these include Rubber powder, Tire Reclaim and Butyl Reclaimed. These tests conducted for evaluation include the Marshall Stability test, Marshall Ratio and Indirect Tensile Strength. The Marshall Test result showed that adding these additives will increase the Marshall Ratio and stability. However, adding tire reclaim and butyl reclaim will give a more effective result than rubber powder. An indirect tensile strength test revealed that adding rubber power and tire reclaim will improve the performance of HMA against moisture susceptibility [8].

2.3.3 Plastic waste

Over the past few years, with the increase in population and development activities, the reliance on plastic has increased significantly. It is being used in almost every sector including but not limited to packaging production, in construction sector, in electrical and electronics sector, in textile industry etc. Consequently, due to its non-biodegradable nature, the disposal of plastic has become an environmental threat, causing hygiene problems and destroying aesthetic views around the world. To deal with this threat, the researchers have been working on a solution where plastic can be used as a recycled material.

The study was conducted in Ghana in 2018 to determine the properties of plastic waste including size, thickness and content percentage that can provide ultimate performance of hot mix asphalt. To do so, the Marshall test and retained strength index were used. The plastic waste was shredded, followed by the separation based on size, thickness and content percentage. Separation based on size was done using passing sieves 3/4”, 1/2”, 3/8”, No. 4, No. 08 and No. 16, for thickness, the waste was divided into four thicknesses of 0.2, 0.5, 0.8 and 1.0mm and the content percentage used by the weight of aggregate was 5%, 10%, 15%, 20% and 25%. The result concluded that Marshall Stability and water resistivity can be improved on account of plastic waste of fine particles, thin thickness and 15% content by weight of total aggregate. Moreover, it can contribute to reducing some of the environmental problems associated with classic plastic waste disposal methods [9].

2.4 Waste Tires Accumulation

Waste tires are becoming one of the primary threats worldwide due to their increase in accumulation and the associated environmental and social concerns. Across the globe, waste tires are considered an undervalued resource that is often disposed of in landfills, which is a major concern.

Approximately 1.5 billion tires are discarded annually after their end-of-life; this figure is expected to rise to 5 billion by 2030. Most of these tires are sent to landfills, burned, or stockpiled, causing various environmental problems. Utilizing waste materials instead of disposing of them can make a significant difference [10].

In Pakistan from 2015 to 2019, the estimated annual waste tire generation ranges between 889 and 1042 million kg as depicted in Fig. 1. The data comes from the Statistics of Pakistan Bureau 2019-2020 and is based on the number of road vehicles in Pakistan.

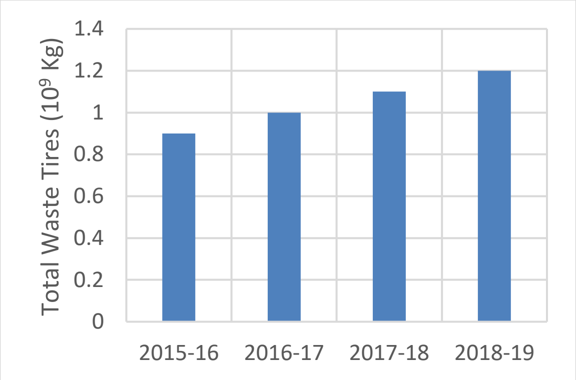

Fig. 1. Annual Generation of Waste Tires, Pakistan [11]

There is an emerging trend of extracting steel fibres from waste tires. The incorporation of waste recycled tire steel (WRTS) fibres into concrete has the potential to generate profit in engineering applications [12].
Research has been conducted on cementitious composites incorporating recycled waste materials. Reusing waste materials in concrete reduces environmental pollution, improves sustainability, and makes the material more economical.

2.5 Conclusive remarks

From the above literature review, following important points can be obtained. A road infrastructure that resists water is necessary, as bituminous mixes containing water tend to fail prematurely. To maintain the integrity of the road, it is essential to design a water-resistant pavement, which incorporates materials that are resistant to water.
Solid tire waste is a non-biodegradable material that causes severe environmental and public health problems. Furthermore, burning tire waste harms the environment by increasing air, water and soil pollution. Therefore, it is necessary to find alternative storage and disposal methods for this huge amount of tire waste to mitigate ecological damage and exhaust available disposal sites [13].
To deal with pavement flooding and environmental threats, this study proposed a solution in the form of the addition of recycled tire rubber crumb as an additive in the asphalt mix.

3 Experimental Program

The study centred on the preparation of two kinds of samples, conventional and modified samples. Modified samples were prepared using recycled tire rubber crumb as an additive. The samples have undergone through Marshal Mix design process in the laboratory at optimum temperatures to evaluate the effect of water on both kinds of samples. During the laboratory work, standard test methods will be employed as they will provide accuracy and validity to our work. The flow chart of the methodology is illustrated in Fig. .

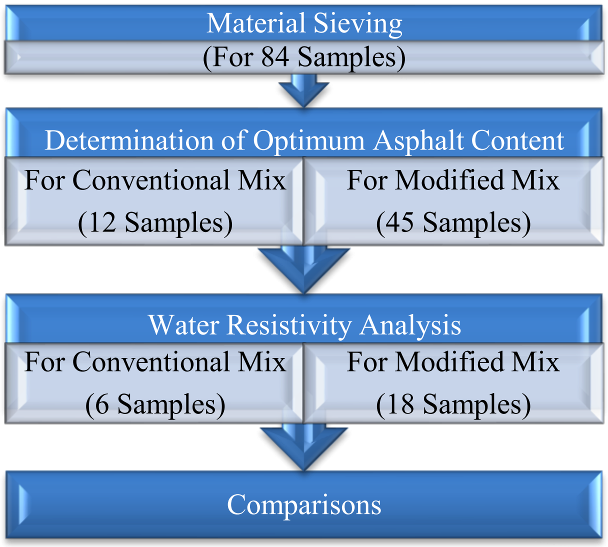

Fig. 2. Methodology – Flow Chart

3.1 Marshal Mix Design

The concept of Marshall Mix design was initially introduced by Bruce Marshall, Highway Department Mississippi, in 1939 and was later refined by the US Army. The test procedure has been standardized by ASTM and is published under the code of ASTM-D1559. The application of the Marshal Test is limited to hot mix asphalt that has penetration grades of asphalt cement and contains the maximum size of aggregate as 25mm.
The objective of the Marshall Mix Design procedure includes the determination of;

1) Density-voids analysis for bituminous mixture
2) Marshall stability and flow value
3) Suitability of bituminous mix as per specified standards.

Apart from the above, retained stability of the samples is also of importance in terms of its durability and resistance against water. A mixture's retained Marshall Stability refers to its ability to

remain stable when exposed to water. It is conducted on the Marshall samples to measure the resistance of the mix towards the water. The retained stability is determined after placing the samples in for 24 hours [14].
The materials used in this research work include bitumen, aggregate and recycled tire rubber crumb (Passing # 50 sieve size). Recycled tire rubber crumb was used in an asphalt mix as an additive. Recycled tire rubber crumb was procured to use as an additive in the modified samples. The rubber that was procured comprised 5%-75% rubber content and 25% to 95% zinc oxide by weight. Its specific gravity lies between the range of 1.4g/cc and 3.4g/cc. Moreover, the rubber was thermosetting and did not melt.
Sieving was performed to get the aggregates of the desired size as specified by NHA. Initially, the aggregates were sieved to determine the optimum asphalt content (OAC) of conventional and modified samples & later on were sieved to determine Retained Marshall Stability.

3.2 Laboratory Procedures

The aggregates were required to prepare 81 samples in total, out of which 12 samples were used to determine the OAC by conventional means, 45 samples were used to determine the OAC by modified means and the remaining 24 samples were used to compare Marshall Stability and Marshall Retained Stability between conventional and modified method. Table presents the total weight of the sample that was required to retain each desired sieve size.

Table 1. Aggregate Sieving

Sieve No.	Sieve Opening (mm)	Pct. Passing	Pct. Retained	Wt. Retained for 01 Sample (gm.)	Wt. Retained for 81 Sample (gm.)
1	25.4	100%	0%	-	-
3/4	19	95%	5%	60	4,860
3/8	9.5	63%	37%	384	31,104
No. 4	4.75	43%	58%	246	19,926
No. 8	2.36	29%	71%	162	13,122
No. 16	1.18	9%	92%	246	19,926
No. 200	0.075	5%	95%	42	3,402
Pan	---	0%	100%	60	4,860
Total sample in grams				**1,200**	**97,200**

The preparation of the specimen was based on the assumption that the possible range of optimum asphalt content (OAC) lies between 3% and 5%. The trial mixture was prepared at an interval of 0.5% over this range. To determine the OAC of conventional and modified samples, the following number of samples were required as mentioned in Table 1

Table 1 Sample Preparation

S. No.	Asphalt Mix Trial Percentage	Conventional Samples	Modified Samples		
			2% Tire Reclaim	4% Tire Reclaim	6% Tire Reclaim
1	3.00%	-	3	3	3
2	3.50%	3	3	3	3
3	4.00%	3	3	3	3
4	4.50%	3	3	3	3
5	5.00%	3	3	3	3
No. of Sample for Determining OAC		**12**	**15**	**15**	**15**
Total No. of Sample for Determining OAC					57

For each sample, 1200gm of aggregates with properly specified gradation are thoroughly dried and heated at 110 °C. Bitumen is added at a mixing temperature of 160 °C to produce a viscosity of 170 ± 20 centistokes, with the first asphalt mix trial percentage that is 3% by weight of aggregate. The aggregates and bitumen are mixed thoroughly in a heated pan using mixing tools. Reheat the mix to

180°C to achieve a viscosity of 280 + 30 centistokes.

The same procedure was followed with 0.5% in asphalt content and for each percentage 3 samples were prepared.

To prepare the mix for the modified sample, a recycled tire rubber crumb of passing #50 sieve size was used as an additive. Crumb was added at 2%, 4%, and 6% by wt. of asphalt, respectively. For adding rubber crumbs, a wet mixing process was used.

Before mixing asphalt with recycled tire rubber crumb, the asphalt was heated to about 150°C and afterwards was mixed with tire crumb maintaining the temperature between 135°C-150°C, allowing asphalt and rubber to mix properly. The mixing process was performed manually.

Compaction of the specimen was performed using a Marshall compaction pedestal as shown in ***Error! Reference source not found.****4*, and the number of blows of the hammer applied on each side of the specimen was 75 considering heavy traffic loading. The resulting specimen was about 4 inches in diameter and 2.5 inches in height. After compaction, the specimens were ejected and allowed to cool.

By applying a standard test procedure to a standard test specimen at 60 °C, the Marshall stability-flow test measures the maximum load resistance and resulting deformation. Under the worst conditions expected in the field, it simulates pavement failure under the most severe conditions.

The sample ejected using a sample ejector was then immersed in a water bath at 60 °C for 30 minutes. Afterwards, the sample was loaded into a Marshall Stability Testing Machine as shown in **Error! Reference source not found.**6, that constantly deforms it at 5 mm per minute until failure occurs. The total maximum load that causes the failure was noted as Marshall Stability and the flow value of a specimen is the deformation at the failure point expressed in 0.01 inch.

After testing of samples, four (04) properties were tested against the asphalt content for each type of sample in this study. These included air voids, Voids in Mineral Aggregates (VMA), Marshall stability and flow. Subsequently, to determine the Optimum Asphalt Content, the Marshall Method design criteria are compared with the mix properties for 5.5% air voids.

3.3 Water resistivity analysis

Each binder type was investigated with six Marshall Specimens containing the optimum binder content. The study examined four levels of rubber content by weight of optimum asphalt content, at 0%, 2%, 4% and 6% respectively.

In each group of six specimens, three specimens were tested under the Marshall standard for Marshall Stability. The remaining three were tested after being immersed in water for 24 hours. The retained Marshall Stability indicates water's effect on mixes. The higher the retained Marshall stability, the greater would be the water resistance.

4 Results and Discussions

4.1 Marshall Test Results

As per specifications of National Highway Authority (NHA) of Pakistan, the asphalt concrete wearing course mixture shall meet the following Marshall Test Criteria as mentioned in Table3.

Table 3. Marshall Test Criteria [15]

Marshall Mix Method	**Criteria**
Compaction, number of blows Each end of the specimen	75
Stability	1000 Kg (Min.), 2204 lb. (Min.)
Flow, 0.25 mm (0.01 inch)	8-14
Percent air voids in the mix	4-7
Percent voids in mineral aggregate	14% (Min.)
Loss of Stability	20% (Max.)

As per NHA specifications, the percentage of air voids in the mix should range between 4% and 7%. Therefore, the asphalt content is determined using against an air void of 5.5% (average of 4% and 7%).

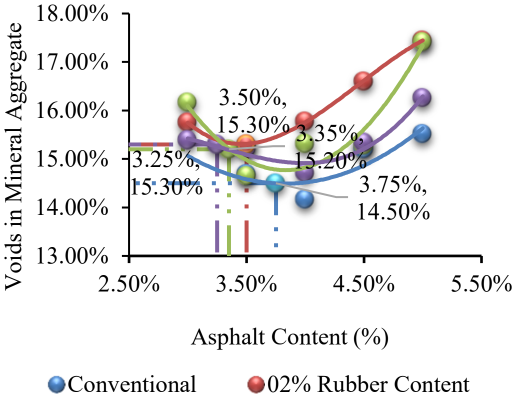

Fig. 3 Asphalt Content vs. VMA

3 shows the change in VMA at different asphalt contents for different types of samples. From these percentages of VMA, we can conclude that modified samples provide better VMA than conventional samples, allowing more space for bitumen to adequately coat each aggregate particle. NHA specifications require a minimum VMA of 14%, so we can conclude that both conventional and modified methods produced results that meet the minimum requirements.

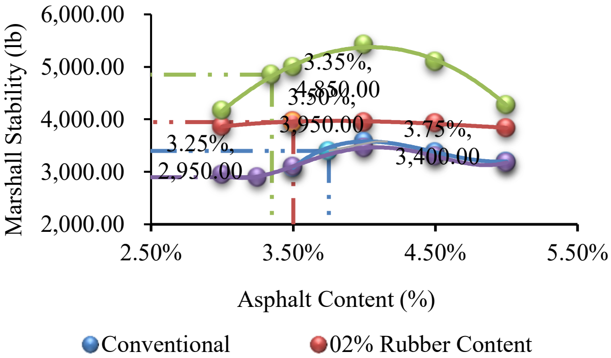

Fig. 4. Asphalt Content vs. Marshall Stability

It can be observed from Fig.4 that rubber content had a prominent impact on the stability of samples. Since the stability of the mix defines the maximum load carried by a compacted specimen at a standard testing temperature; we can conclude that adding 2% and 4% of additive will provide better resistance against load. Furthermore, it is also shown that the behaviour of samples, with regards to changes in asphalt content, also changes when the rubber content is varied. Hence, more investigation would be required to address this phenomenon.

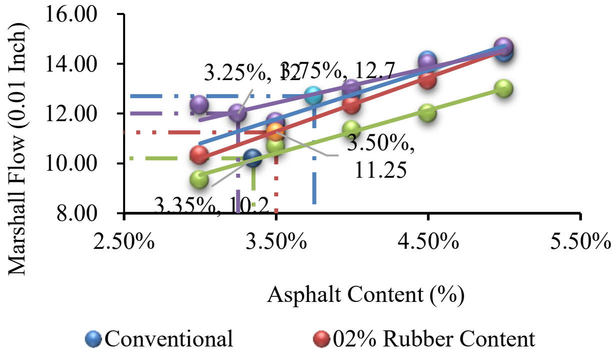

Fig. 5. Asphalt Content vs. Flow

Fig. 5 shows that increase in rubber content decreases the flow value irrespective of the asphalt content. The flow also increases with the increase in asphalt content for all types of samples. The NHA specifies a flow rate between 8 and 14, so we can conclude that all the conventional and modified mixes meet this standard.
Using the graphs analysed above, Table 55 shows the optimum asphalt content for each mixture for air void ratio of 5.5% as per NHA specifications, as explained above. Taking into account the results, we can conclude that crumb rubber contributes to a reduction in asphalt content.

Table 5. OAC for Different Types of Samples

Type of Asphalt Mixture	Unmodified Asphalt	Modified Asphalt		
		2% Rubber	4% Rubber	6% Rubber
Optimum Asphalt Content (%)	3.75%	3.5%	3.35%	3.25%

4.2 Water Resistance Analyses

Based on the OAC obtained above, twenty-four (24) samples were cast, six for each binder type group. Three samples were tested under Marshall Standard (unsoaked condition) and the remaining three after 24 hours of immersion in water (soaked condition). Table 6 depicts the results obtained through sample testing under soaked and unsoaked conditions corresponding to optimum asphalt for conventional and modified methods. It also shows the ratio of stability to flow, which indicates each mix's stiffness. The study indicates that when rubber is introduced into the asphalt mix, stability is improved over conventional mixes, and it also indicates that 4% rubber content is optimal for stability.

Table 6. Water Resistance Results

Mix Type	OAC (%)	Marshall Stability (lb.)		Marshall Flow (0.01 Inch)		Marshall Quotient (lb./in)	
		Unsoaked	Soaked	Unsoaked	Soaked	Unsoaked	Soaked
Conventional	3.75	3,100	2,549	12.70	13.67	244	186
2% RC	3.50	3,950	3,284	11.25	12.33	351	266
4% RC	3.35	4,850	4,124	10.20	12.67	475	326
6% RC	3.25	2,950	2,590	12.00	12.50	246	207

Moreover, we can also conclude that adding 4% of rubber content provides the least deformation. The stiffness of the mixture is indicated by Marshall's Quotient. The higher Marshall's Quotient value indicates lower water susceptibility. From Table 6, it can be said that 4% of rubber content will provide the least water susceptibility.

4.3 Retained & Loss of Stability

Retained and Loss of Stability are the measures to determine pavement resistivity against water. The higher the retained stability, the higher the resistance. Table 7 presents the Retained and Loss of Stability data. The maximum acceptable loss of stability is taken to be 20% as per design practice (Jweihan, 2023).

Table 7. Retained & Loss of Stability

Mix Type	Unsoaked Stability (lb.)	Soaked Stability (lb.)	Retained Stability
Conventional	3,100	2,549	82.24%
2% RC	3,950	3,284	83.13%
4% RC	4,850	4,124	85.03%
6% RC	2,950	2,590	87.80%

Table 7 shows that the highest retained stability was attained at 6% rubber content. However, given the above analysis of stability and flow in the previous sub-section, 4% of the additive is considered optimal, resulting in the retained stability of 85% with a loss of 15% which is under the maximum allowable limit.

5 Conclusions and Recommendations

With Marshall Mix Design, the following effects of recycled tire rubber crumb on asphalt mix were achieved:

1. For 0%, 2%, 4%, and 6% of rubber content, the optimal asphalt content (OAC) was 3.75%, 3.5%, 3.35%, and 3.25% respectively.
2. The more recycled tire crumb rubber was added, the lower the optimum asphalt content was required.
3. A mixture having 4% rubber content and 3.35% optimum asphalt provided optimal Marshall Stability and was least susceptible to water as it has the highest Marshall's Quotient.
4. Loss of stability is minimal at a rubber content of 6%; however, Marshall's stability is almost equal to that of conventional mixes.
5. Retained Marshall Stability for 6% rubber content is higher, indicating higher water resistance compared to other mixes; however, Marshall Stability is relatively low.
6. Retained Marshall Stability is comparatively high for modified mixes, which indicates that recycled tire crumb rubber improves asphalt concrete wearing course water resistance.
7. Both conventional and modified mixes meet all of NHA's requirements.

Based upon the above results, following recommendations are made.

1. Recycled tire crumb rubber is recommended as an additive in asphalt mixtures, as all test results are within standard requirements.
2. The addition of recycled tire crumb rubber tends to increase the stability and quality of the asphalt mixture. A decrease in flow and an increase in stability indicate this.
3. To improve pavement stability and water resistance, it is recommended to add 4% rubber content.

4. Therefore, using recycled tire rubber crumb in asphalt mixture can help in achieving the 9th sustainable development goal i.e., Innovative industry and infrastructure.

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The authors equally contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

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