A Comparative Study of Traditional Asphalt and Flexible Pavement with Rubber Crumb in Terms of Cost and Strength

CRYSTEL G. NICDAO[1], PAULA JOY B. MALLARI[2], MIKO T. RAZON[3], JEFFERSON B. GUINTO[4], KLINT LEONARD G. CUNANAN[5], ADRIAN R. BRIONES[6], PRINCESS KIMBERLY C. SABINIANO[7], CARL JASON A. CORONEL[8]
[1, 2, 3, 4, 5, 6, 7, 8] *Don Honorio Ventura State University, Philippines*

Abstract- Asphalt, a popular paving material used for various applications, has taken on an increasingly significant role in promoting sustainability and environmental responsibility. One such initiative involves the incorporation of recycled rubber from scrap tires into the mix, creating a more durable and flexible pavement structure. With the growing concern over the disposal of scrap tires, using rubber waste in pavement structures is becoming a vital solution for building a more sustainable environment. By reducing the amount of non-biodegradable waste in landfills and promoting the reuse of materials, asphalt is playing a critical role in creating a more sustainable future. This experimental study sought to evaluate the cost and strength of traditional asphalt and flexible pavement with rubber crumbs, using the Marshall Stability test to assess its flow, density, and void content. The study has the following main objectives: to determine the physical and mechanical properties of Traditional Asphalt and Flexible Pavement with Rubber Crumbs; to determine the strength of Traditional Asphalt and Flexible Pavements with Rubber Crumbs; and to execute a cost analysis of Traditional Asphalt and Flexible Pavement with Rubber Crumbs and compare results. Marshall Stability test will be done on the samples of traditional asphalt and flexible pavement with rubber crumbs considering different concentrations (3%, 6%, and 9%) to estimate the strength of the pavement. The addition of rubber crumbs to asphalt mixtures resulted in lower stability values, with mixtures containing 3% rubber having a higher bulk specific gravity compared to traditional asphalt. The addition of rubber crumbs compromises the stability of the mixture, resulting in the creation of voids, lower density, and stability. As the percentage of rubber in asphalt increases, it becomes less durable, more permeable, and more susceptible to deformation.

I. INTRODUCTION

Roadways are wide and improved surface used by vehicles and pedestrians to travel to one place to another. It is an important infrastructure that connects all routes and organizes the mode of transportation. Since the world continuously changing and developing, professional Engineers particularly Highways Engineers provides an efficient, durable and safe road transport for people by choosing the construction materials with excellent quality yet cost-effective and constantly learning to enhance new materials. Roads hold heavy traffics and carry the applied forces given by a particular vehicle

Construction materials, such as asphalt and concrete, are made using natural resources that are finite and valuable. The pavement used on roads and highways is created by combining bitumen with an aggregate that binds together sand, stone, and gravel. As the world population and economy continue to grow, the construction of new roads becomes essential to support transportation needs. However, the upsurge in the quantity of automobiles traversing the roads results in a corresponding surge in the production of discarded tire waste. According to Hailstone, J. (2022) reported that approximately one billion tires reach the end of their useful life annually, while landfills and stockpiles worldwide currently hold around four billion discarded tires. Improper disposal of these tires can create environmental hazards, such as polluting landfills, emitting toxic gases, and provide breeding grounds for mosquitoes.

To mitigate this issue, researchers have been exploring ways to recycle and repurpose waste tires. An encouraging approach entails incorporating crumb rubber as a supplementary component in road construction endeavors. Crumb rubber, derived from the shredding and grinding of discarded tires into small fragments, can be combined with various construction materials such as aggregates and bitumen. This amalgamation results in the creation of a road surface that exhibits enhanced durability and flexibility. The inclusion of crumb rubber enhances the pavement's elasticity and resilience against fatigue, resulting in diminished cracking and an extended lifespan of the pavement.

As stated by (Naha S. Mahaan et al., 2012), the report discusses the potential benefits of using recycled tire rubber in asphalt pavements, such as improved pavement performance and durability, reduced road noise, and reduced tire waste. Various methods of incorporating rubber into asphalt, such as the wet process and dry process, are explained in the report, along with the challenges and limitations associated with each method. The report includes case studies and field trials that demonstrate the effectiveness of rubberized asphalt in various road conditions and climates, as well as the economic and environmental benefits of its use. It is concluded that rubberized asphalt is an effective solution for improving pavement performance and reducing waste, but more research is needed to optimize the design and application of rubberized asphalt mixes.

The study aims to conduct a comparative analysis between traditional asphalt and flexible pavement with rubber crumbs. The focus of the comparison will be on the cost and strength analysis of both materials. The researchers aim to provide accurate information and results by employing a comprehensive methodology. The comparison of results from this study will enable a more informed decision-making process regarding the selection of the most suitable material for a given application. The study will be conducted using rigorous research methods, including a detailed literature review, material testing, and data analysis. Ultimately, this research endeavor will contribute to the progression of knowledge in the realm of pavement engineering, offering valuable insights for the planning and construction of transportation infrastructure.

II. METHODOLOGICAL FRAMEWORK

This chapter presents the research design, sample making, sample testing and data analysis and evaluation to discuss and provide specific information and understanding regarding the findings of the study.

A. Research Design

The researchers used an intervention research methodology in this part, specifically an experimental study design. This also covered sample development for the materials, tools, and equipment used. The data gathered were derived from the various testing procedures performed by comparing the two materials. The researchers also used a quantitative approach to compare the two materials which is the asphalt and flexible pavement with rubber crumbs. The data collection will be in the form of a test.

B. Sample Making

The procedures in sample making were made in the accordance of the different standard procedures and American Society for Testing and Materials (ASTM).

C. Sample Testing

The Marshall Stability test was done on the traditional asphalt and flexible pavement with rubber crumbs considering different concentrations (3%, 6%, and 9%) to estimate the strength of the pavement. The test in the study involves preparing cylindrical asphalt mix specimens and subjecting them to a load until they reached the point of maximum load. The load is known as the Marshall stability and indicates the mixture strength, while the deformation at this point is known as the Marshall flow and indicates the mixture's deformation properties. The testing procedure was followed in accordance with the ASTM standard for the Marshall Stability Test of Asphalt Mixtures ASTM D6927-15, Standard Test Method for Marshall Stability and Flow of Asphalt Mixtures.

D. Data Analysis and Evaluation

The study focused on three main phases: planning, sample creation, and result evaluation. In the planning phase, materials such as Bitumen, Aggregates, and rubber crumbs were procured, and essential tools and equipment were provided by the testing center. The second phase involved creating two sample materials through various tasks like measuring, cooking, compacting, molding, bathing, and measuring physical properties. Different concentrations of rubber were used in the samples to determine the optimal composition. In the final phase, the researchers statistically analyzed the data provided by the testing facility and compared the traditional asphalt and flexible pavement with rubber crumbs in terms of cost and strength. The gathered data served as the foundation for further evaluation and a cost analysis was conducted to conclude the study.

III. RESULTS, FINDINGS, AND DISCUSSIONS

In this chapter, the results of the experiments and testing described in the previous chapter are presented and discussed. Comparisons will be provided in terms of their cost and strength regarding their differences.

Table 3.1 Test Report on Traditional Asphalt and Flexible Pavement with Rubber Crumbs

REPORT ON TRADITIONAL ASPHALT AND FLEXIBLE PAVEMENT WITH RUBBER CRUMBS						
SIEVE ANALYSIS Sieve Size		RESULTS (% of Rubber Crumbs)				JOB-MIX SPECIFICATION
inches	mm	0%	3%	6%	9%	
1	25	100.0	100	100	100	100
3/4	19	95	95	95	95	95-100
½	12.5	80	69	80	70	68-86
3/8	9.5	75	63	64	58	56-78
#4	4.75	58	32	35	40	38-60
#8	2.36	45	30	46	32	27-47
#16	1.18	33	25	32	27	18-37
#30	0.6	19	13	26	21	11-28
#50	0.3	7	8	12	9	6-20
#200	0.075	1	1	1	6	0-8
Bitumen Content % by weight of total mix		5.19	5.11	5.11	5.10	6-8
Bulk Specific Gravity		2.419	2.440	2.314	2.245	
Air Voids, %		3.4	2.5	7.6	10.3	3-5
Flow, 0.01 inch		13.3	9.8	7.9	7.1	8-14
Marshal Stability, psi						
30 mins.		2263	1865	1451	978	1800 min

This table shows the test report of traditional asphalt and flexible pavement with rubber crumbs in accordance with job mix specifications.

Sieve Size	Grading Requirement	Asphalt Mixture with 3 %			Traditional Asphalt		
		Wt.	Wt.	%	Wt.	Wt.	%
25mm	100	-	1078.8	100	-	995.4	100
19mm	95-100	53.9	1024.9	95	49.8	945.6	95
12.5mm	68-86	280.5	744.4	74	149.3	796.3	80
9.5mm	56-78	64.7	679.6	68	49.8	746.5	75
4.75mm	38-60	334.4	345.2	35	169.2	577.3	58
2.36mm	27-47	21.6	323.6	32	129.4	447.9	45
1.18mm	18-37	53.9	269.7	27	119.4	328.5	33
0.6mm	11-28	129.5	140.2	14	139.4	189.1	19
0.3mm	6-20	53.9	86.3	8	119.4	69.7	7
0.075mm	0-8	76.6	9.7	0.9	62.7	7.0	0.7

The table displays that the Marshall Test of Traditional Asphalt sample contains 1146 g of aggregates and 54 g of asphalt. In contrast, the Flexible pavement with rubber crumbs has 1112 g of aggregates and 34 g of rubber crumbs, while maintaining the same amount of asphalt. The grading requirement was met as per Item 310 B of the DPWH Standard Specifications for Highways, Bridges, and Airports

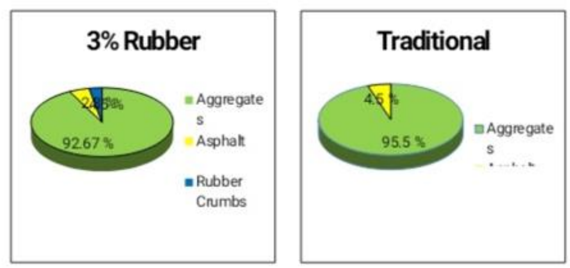

Figure 3.1 depicts the composition breakdown of each mixture in the Marshall Test. The Traditional Asphalt sample consists of 1146 g of aggregates and 4.5% asphalt. In contrast, the Flexible pavement with rubber crumbs has a total weight of 1112 g of aggregates, with 34 g or 2.8% attributed to rubber crumbs.

B. Table 3.3 Sieve Analysis after Extraction

Sieve Size	Grading Requirements	Asphalt Mixture with 6 %			Traditional Asphalt		
		Wt.	Wt.	%	Wt.	Wt.	%
25mm	100	-	1018.9	100	-	995.4	100
19mm	95-100	50.9	968.0	95	49.8	945.6	95
12.5mm	68-86	152.8	815.1	80	149.3	796.3	80
9.5mm	56-78	163.0	652.1	64	49.8	746.5	75
4.75mm	38-60	295.5	356.6	35	169.2	577.3	58
2.36mm	27-47	112.1	468.7	46	129.4	447.9	45
1.18mm	18-37	142.7	326.1	32	119.4	328.5	33
0.6mm	11-28	61.1	264.9	26	139.4	189.1	19
0.3mm	6-20	142.7	122.3	12	119.4	69.7	7
0.075mm	0-8	115.1	7.1	0.7	62.7	7.0	0.7

The second table reveals that the Marshall Test results for the Traditional Asphalt sample indicate a composition of 1146 g of aggregates and 54 g of asphalt. In contrast, the Flexible pavement with rubber crumbs exhibits 1078 g of aggregates and 68 g of rubber crumbs, while containing an equivalent amount of asphalt. Moreover, it is noteworthy that the grading requirement was duly satisfied as per the guidelines prescribed in Item 310 B of the DPWH Standard Specifications for Highways, Bridges, and Airports.

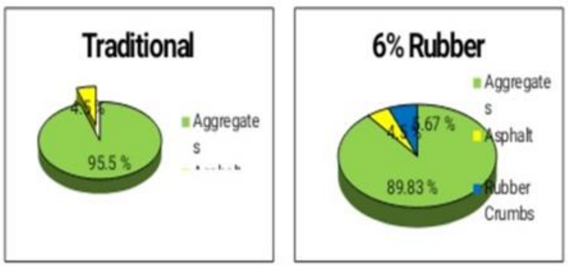

Figure 3.2 shows the percentage of each mixture the Marshall Test of Traditional Asphalt sample contains 1146 g of aggregates and 4.5 % of asphalt while the Flexible pavement with rubber crumbs has a total weight of 1078 g of aggregates and 68 g or 5.67 % of Rubber crumbs.

C. Table 3.4 Sieve Analysis after Extraction

Sieve Size	Grading Requirements	Asphalt Mixture with 9%			Traditional Asphalt		
		Wt.	Wt.	%	Wt.	Wt.	%
25mm	100	-	959.1	100	-	995.4	100
19mm	95-100	48.0	911.1	95	49.8	945.6	95
12.5mm	68-86	239.8	671.3	70	149.3	796.3	80
9.5mm	56-78	115.1	556.3	58	49.8	746.5	75
4.75mm	38-60	172.6	383.6	40	169.2	577.3	58
2.36mm	27-47	76.6	306.9	32	129.4	447.9	45
1.18mm	18-37	48.0	258.9	27	119.4	328.5	33
0.6mm	11-28	57.5	201.4	21	139.4	189.1	19
0.3mm	6-20	115.1	86.3	9	119.4	69.7	7
0.075mm	0-8	28.8	57.5	6	62.7	7.0	0.7

The third table presents the Marshall Test results for the Traditional Asphalt sample, indicating a composition of 1146 g of aggregates and 54 g of asphalt. In contrast, the Flexible pavement with rubber crumbs consists of 1043 g of aggregates and 103 g of rubber crumbs, while maintaining an equal amount of asphalt. Additionally, it is worth noting that the grading requirement has been duly met in accordance with the guidelines prescribed in Item 702 B of the DPWH Standard Specifications for Highways, Bridges, and Airports.

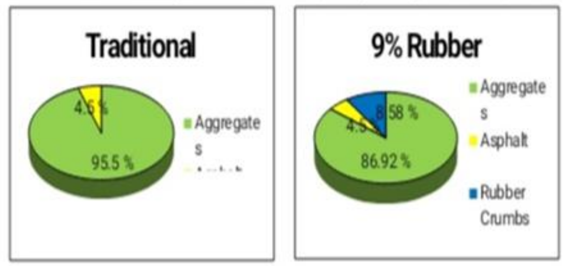

Figure 3.3 shows the percentage of each mixture the Marshall Test of Traditional Asphalt sample contains 1146 g of aggregates and 4.5 % of asphalt while the Flexible pavement with rubber crumbs has a total weight of 1043 g of aggregates and 103 g of Rubber crumbs.

D. Table 3.5 Marshall Test of 3% Flexible Pavement with Rubber Crumbs and Traditional Asphalt Pavement

		Asphalt Mixture with				Traditional Asphalt			
SPECIMEN		1	2	3	Ave.	1	2	3	Ave.
AC by Wt. of mix	%				5.11				5.19
Weight in Air	gram	1173	1184	117		1153	1209	1206	
Weight in water	gram	690.	697.	692.		690.0	707.4	717.4	
Weight in SSD	gram	1176	1180	117		1154.	1219.	1217	
Bulk Volume	gram	486	482	480		465	512	500	
Bulk Specific Gravity (		2.41	2.45	2.45	2.440	2.482	2.361	2.414	2.41
Max. Theoretical					2.503				2.50
Air Voids (Pa)	%				3.4				3.4
Voids in Mineral Aggts.	%				18.5				19.3
Voids filled with	%				86.4				82.6
Height of Specimen	mm	64.8	66.5	65.5		57.8	62.2	62.5	
		30 mins.				30 mins.			
Dial Reading	kn	36	37	35		42	46	43	
	kn	8.73	8.97	8.49		10.18	11.15	10.43	
Stability measured	lbs.	1963	2018	190		2291	2509	2345	
Correlation ratio		0.97	0.93	0.95		0.95	0.95	0.95	
Stability corrected	lbs.	1904	1877	181	1865	2171	2393	2223	2263
Flow	.01	10.3	9.6	9.6	9.8	14.2	13.2	12.6	13.3

The provided table displays the outcomes of the Marshall Test carried out on both the traditional asphalt mixture and the flexible pavement containing 3% rubber crumbs. This test evaluated various significant properties of the asphalt mixture, such as voids filled with asphalt (VFWA), air voids, voids in mineral aggregates (VMA), density, stability, and flow.

E. Table 3.6 Marshall Test of 6% Flexible Pavement with Rubber Crumbs and Traditional Asphalt Pavement

		Asphalt Mixture with 6 %				Traditional Asphalt Mixture			
SPECIMEN		1	2	3	Ave.	1	2	3	Ave.
AC by Wt. of	%				5.11				5.19
Weight in Air	gra	1176	1179	1183		1153	1209	1206	
Weight in	gra	671.0	673.1	677.0		690.0	707.4	717.4	
Weight in SSD	gra	1181	1183	1186		1154.5	1219.5	1217	
Bulk Volume	gra	510	510	509		465	512	500	
Bulk Specific		2.306	2.312	2.324	2.31	2.482	2.361	2.414	2.41
Max.					2.50				2.50
Air Voids (Pa)	%				7.6				3.4
Voids in	%				22.7				19.3
Voids filled	%				66.8				82.6
Height of	mm	65.1	64.3	64.8		57.8	62.2	62.5	
		30 mins.				30 mins.			
Dial Reading	kn	27	29	26		42	46	43	
	kn	6.550	7.035	6.307		10.189	11.159	10.431	
Stability	lbs.	1472	1582	1418		2291	2509	2345	
Correlation		0.96	0.98	0.98		0.95	0.95	0.95	
Stability	lbs.	1414	1550	1390	1451	2171	2393	2223	2263
Flow	.01	8.2	7.6	7.8	7.9	14.2	13.2	12.6	13.3

The presented table shows the results of the Marshall Test conducted on traditional asphalt mixture and flexible pavement with 6% rubber crumbs. The test determined several important properties of the asphalt mixture, including voids filled with asphalt (VFWA), air voids, and voids in mineral aggregates (VMA), density, stability, and flow.

F. Table 3.7 Marshall Test of 9% Flexible Pavement with Rubber Crumbs and Traditional Asphalt Pavement

		Asphalt Mixture with 3 %				Traditional Asphalt Mixture			
SPECIMEN		1	2	3	Ave.	1	2	3	Ave.
AC by Wt.	%				5.10				5.19
Weight in	gram	1186.5	1174	1178		1153	1209	1206	
Weight in	gram	665.0	651.9	654.9		690.0	707.4	717.4	
Weight in	gram	1190	1176	1182		1154.5	1219.5	1217	
Bulk	gram	525	524	527		465	512	500	
Bulk		2.260	2.240	2.235	2.245	2.482	2.361	2.414	2.419
Max.					2.503				2.503
Air Voids	%				10.3				3.4
Voids in	%				25.0				19.3
Voids filled	%				58.8				82.6
Height of	mm	65.2	66.1	66.7		57.8	62.2	62.5	
		30 mins.				30 mins.			
Dial Reading	kn	19	20	18		42	46	43	
	kn	4.6094	4.852	4.3668		10.1892	11.1596	10.4318	
Stability	lbs.	1036	1091	982		2291	2509	2345	
Correlation		0.96	0.94	0.93		0.95	0.95	0.95	
Stability	lbs.	995	1025	913	978	2171	2393	2223	2263
Flow	.01inch	6.5	6.8	7.9	7.1	14.2	13.2	12.6	13.3

This table presents the results of the Marshall Test conducted on traditional asphalt mixture and flexible pavement with 9% rubber crumbs. The test determined several important properties of the asphalt mixture, including voids filled with asphalt (VFWA), air voids, and voids in mineral aggregates (VMA), density, stability, and flow.

IV. PHYSICAL AND MECHANICAL PROPERTIES

A. Voids filled with Asphalt (VFWA)

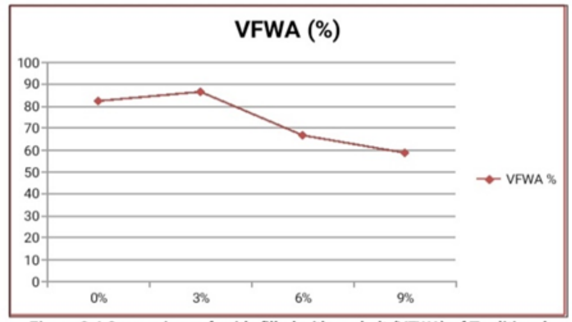

Figure 3.4 Comparison of voids filled with asphalt (VFWA) of Traditional Asphalt and Flexible pavement with Rubber Crumbs

The provided figure displays the Voids Filled with Asphalt (VFWA) values obtained from the test results of traditional asphalt and flexible pavement with different concentrations of rubber crumb (3%, 6%, and 9%). The VFWA value for traditional asphalt is 82.6%, while the values for flexible pavement with rubber crumb content are 86.6%, 66.8%, and 58.8% for 3%, 6%, and 9% rubber crumb content, respectively.

The results suggest that an increase in the percentage of rubber crumb content leads to an increase in VFWA due to the additional spaces created by the rubber crumbs in the compacted paving mixture, which allows for the movement of the bitumen. Consequently, the asphalt fills the voids in the mixture, resulting in a reduction of overall pavement stability as the rubber crumb content increases.

B. Air Voids

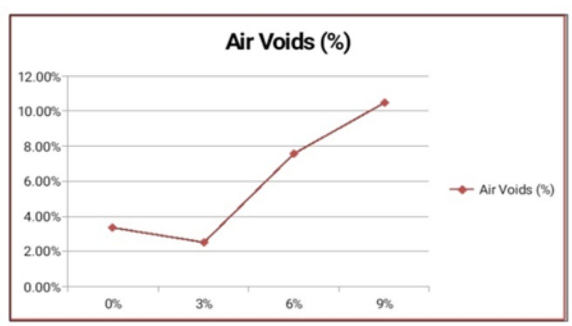

Figure 3.5 Comparison of Air voids of Traditional Asphalt and Flexible pavement with Rubber Crumbs

Upon comparison of the air void test results, it was found that traditional asphalt has an air voids value of 3.4%, whereas flexible pavement with rubber crumbs at concentrations of 3%, 6%, and 9% exhibit maximum air voids values of 2.517%, 7.6%, and 10.5%, respectively. Based on these results, it can be deduced that the traditional asphalt mixture met the job-mix specification, whereas the flexible pavement with rubber crumbs at various concentrations (3%, 6%, and 9%) failed to meet the specification. This indicates that higher concentrations of rubber crumbs result in increased air voids. This conclusion aligns with previous research and the testing conducted by the researchers.

Higher air voids can lead to reduced permeability in the asphalt mixture, as they provide a pathway for air and water to enter. This can have a substantial impact on the longevity and effectiveness of the asphalt pavement. Therefore, it is essential to maintain optimal air voids levels in the mixture to ensure the longevity and effectiveness of the pavement.

C. Marshall Stability

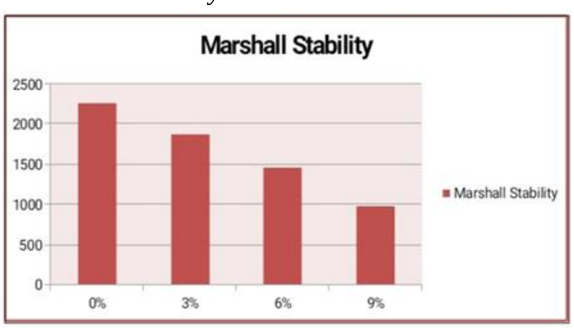

Figure 3.6 Comparison of Marshall Stability of Traditional Asphalt and Flexible pavement with Rubber Crumbs

Upon analysing the Marshall Stability test results presented in the table, it was observed that the traditional asphalt mixture containing 5.19% (AC) by weight of the mix exhibits an optimum stability value of 2263 lb. However, the flexible pavement incorporating 3% rubber crumbs (RC) with 5.11% AC by weight of mix has an optimum stability value of 1865 lb. The flexible pavement with 6% RC and 5.11% AC by weight of mix has an optimum stability value of 1451 lb., while the flexible pavement with 9% RC and 5.10% AC by weight of mix exhibits an optimum stability value of 978 lb.

The test results indicate that as the rubber crumb content increases, the stability of the asphalt mixture decreases. This is attributed to the fact that higher concentrations of rubber crumbs reduce the touch point between the aggregates, resulting in a stiff mixture that contributes to the decrease in stability. Furthermore, low stability values indicate a low quality of aggregates used in the mixture. It is crucial to maintain the stability of the asphalt mixture to ensure the longevity and durability of the pavement.

D. Flow

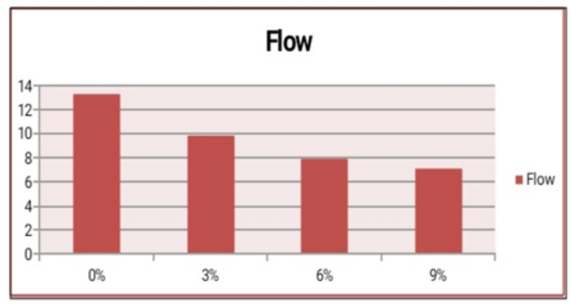

Figure 3.7 Comparison of Flow of Traditional Asphalt and Flexible pavement with Rubber Crumbs

After analyzing the flow test results presented in the table, it was noted that the flow test value of the asphalt mixture decreased as the percentage of rubber crumbs increased. The traditional asphalt mixture had a flow test value of 13.3, while the flexible pavement mixtures with 3%, 6%, and 9% rubber crumbs had flow test values of 9.8, 7.9, and 7.1, respectively. Additionally, it was noted that the traditional asphalt mixture specimens only met the job mix specification.

These results indicate that with an increase in the percentage of rubber crumbs in the mixture, the flow of the asphalt mixture decreases. This can result in the mixture becoming excessively rigid or challenging to effectively place and compact. The flow of asphalt is crucial for assessing the ability of an asphalt mixture to deform under traffic stresses and strains. Excessive deformation caused by high flow can lead to pavement surface rutting, while too low a flow can result in a stiff mixture that is prone to cracking under repeated traffic loads. Therefore, optimizing and controlling the flow of asphalt is essential for ensuring sufficient deformation and rutting resistance, as well as adequate stiffness to resist cracking. Therefore, it is essential to carefully consider the appropriate percentage of rubber crumbs to be added to the asphalt mixture to achieve the desired flow and performance characteristics.

V. SAMPLE CALCULATION FOR 1 KM ROAD CONSIDERING WIDTH OF 6.10 METERS

G. Table 3.8 Cost Analysis of Traditional Asphalt and Flexible pavement with Rubber Crumbs

TRADITIONAL ASPHALT PAVEMENT				
Materials	Qty.	Unit	Unit Cost	Material Cost
Bitumen	38,149	kg	Php 55.56/ kg.	Php 2, 119, 558.44
Aggregates	312	cu.m	Php 879.58/ cu.m	Php 274, 428
MATERIAL TOTAL COST				Php 2, 393, 986.44
LABOR COST (30% of MTC)				Php 718, 196
FLEXIBLE PAVEMENT WITH RUBBER CRUMBS (3 %)				
Materials	Qty.	Unit	Unit Cost	Material Cost
Bitumen	38,149	kg	Php 55.56/ kg.	Php 2, 119, 558.44
Aggregates	303	cu.m	Php 879.58/ cu.m	Php 266, 512. 74
Rubber	9.36	cu.m	Php 85/ cu.m	Php 795.6
MATERIAL TOTAL COST				Php 2, 386, 866.78
LABOR COST (30% of MTC)				Php 716,060

This table shows the cost analysis of traditional asphalt and flexible pavement with 3% of rubber crumbs. As you can see, 6% and 9% are not included in this table since they did not pass the Marshall test. The cost for the material has changed for both mixtures due to the additional material, which is the rubber crumbs, used as a substitute for aggregate. The traditional asphalt mixture has a total cost of Php 2, 393, 986.44, while the flexible pavement with rubber crumbs or the new material decreased to Php 2, 386, 866.78, resulting in a difference of PHP 7,119.66. For the manpower, 30% of the total cost is for labor cost. 3% of aggregates have been replaced by 3% rubber crumbs for the Marshall test. The Marshall Stability value of the asphalt mixture without rubber crumbs has an average of 2263 lbs with a bulk specific gravity of 2.419, and the flexible pavement with 3% of rubber crumbs has an average of 1865 with a bulk specific gravity of 2.450. Both specimens passed the minimum required design criteria of 1800 lbs within 30 minutes of compaction. For the flow of traditional asphalt mixture, it has a value of 13.3 while flexible pavement with 3% of rubber crumbs has a value of 9.8. Both materials passed the job-mix design criteria.

VI. RECOMMENDATIONS

As environmental concerns continue to grow, there is a pressing need to find innovative and sustainable solutions to reduce waste and promote eco-friendly practices. Here are some recommendations for the future researchers;

Consider adding additional variables: A potential suggestion for future researchers is to consider adding additional variables to their comparative study of traditional asphalt and flexible pavement with rubber crumbs. While cost and strength are important factors to compare, there may be other variables that could impact the performance and effectiveness of these pavement types. Expanding the study to include factors such as durability, sustainability, and environmental impact could provide a more comprehensive understanding of the advantages and drawbacks of each pavement type.

Include long-term monitoring: To ensure a thorough evaluation of the effectiveness and cost-effectiveness of traditional asphalt and flexible pavement with rubber crumbs, it is essential to conduct long-term monitoring to compare their lifespan. Such monitoring for several years can facilitate the assessment of their durability and performance over time.

Explore alternative uses of rubber crumbs: Another potential avenue of research is to explore alternative uses of rubber crumbs. Rubber crumbs are a byproduct of recycled tires and can be used in a variety of applications beyond pavement. Investigating other potential uses of rubber crumbs could provide a more comprehensive understanding of their value and impact.

Consider using the wet process: One potential advantage of the wet process is that it may be more effective at incorporating the rubber crumbs into the pavement mixture, resulting in a more uniform and consistent mixture. This can lead to improved strength and durability of the pavement over time. Additionally, the wet process can be less labor-intensive than the traditional dry process, as it can be applied using equipment such as a slurry seal machine.

CONCLUSION

The addition of scrap tire to asphalt-aggregate mixes resulted in consistently lower Marshall Stability values compared to the traditional asphalt mixes without any tire. This occurs because rubber crumb is less rigid than crushed-stone aggregates, leading to decreased stability in the asphalt-aggregate-tire mixes. As a consequence, voids are formed, resulting in lower density and reduced mix stability.

The incorporation of rubber crumbs in flexible pavement mixtures resulted in a lower stability compared to the traditional asphalt mixture without any tire. The stability of the flexible pavement mixtures with 3%, 6%, and 9% rubber crumbs were 1865 lb, 1451 lb, and 978 lb, respectively, within 30 minutes of compaction. This is significantly lower than the stability of the traditional asphalt mixture which had a stability of 2263 lb. Therefore, it can be concluded that the addition of rubber crumbs in flexible pavement mixtures decreased their stability in comparison to the traditional asphalt mixture without any tire.

The bulk specific gravity of flexible pavement with 3% rubber crumbs has a higher result compared to the traditional asphalt for Marshall Stability Test. whereas those with 6% and 9% rubber crumbs show lower results than the traditional one. Therefore, considering the outcomes, it can be inferred that the asphalt mixture containing 3% rubber crumbs demonstrates the highest effectiveness among the three tested variations. Consequently, it is recommended for utilization.

In conclusion, as the percentage of rubber in asphalt increases, more air voids will be present in the mixture, making it less permeable and allowing for the entry of damaging air and water. Furthermore, the increased rubber content can result in a stiff surface that is more susceptible to deformation and less durable in the long run.

REFERENCES

[1] Abdallh. A. A. Lhwaint , et al.,(.2017). "Analysing Properties of Asphalt Concrete Modified with Crumb Rubber Compare to Other Mixture". The Third International Conference on Civil Engineering Research (ICCER) (PDF) Analysing Properties of Asphalt Concrete Modified with Crumb Rubber Compare to Other Mixture (researchgate.net)

[2] ASTM International. (2021). ASTM D6927-21 Standard Test Method for Marshall Stability and Flow of Asphalt Mixtures. Retrieved May 7, 2023, from https://www.astm.org/standards/d6927

[3] Everten. (n.d.). Bakemaster rectangular deep cake pan 35x24x5cm. Retrieved from https://www.everten.com.au/bakemaster-rectangular-deep-cake-pan-35x24x5cm.html

[4] Ferrovial. (n.d.). Asphalt. Retrieved May 7, 2023, from https://www.ferrovial.com/en/resources/asphalt/

[5] Hailstone, J. (2022, March 18). What happens when tires reach the end of the road? Forbes. Retrieved May 30, 2023, from https://www.forbes.com/sites/jamiehailstone/2022/03/18/what-happens-when-tires-reach-the-end-of-the-road/amp/

[6] Henglong Zhang et al., (2022). "An innovative and smart road construction material: thermo chromic asphalt binder". New Materials in Civil Engineering. https://doi.org/10.1016/B978-0-12-818961-0.00022-3

[7] Johnson, T. A. (2016). "Waste Tire as an Asphalt Cement Modifier for Road Pavement".Journal of Environmental Engineering,142(10),04016049.doi: 10.1061/(ASCE)EE.1943-7870.0001091

[8] Jones, E. L. (2015). "Effect of Temperature and Time Parameters on the Chemical Profile of Asphalt Fumes". Journal of Chemical Engineering Data, 60(1), 226-235. doi: 10.1021/je5008819

[9] Kashif and Sumit Rana (2016). "A review of Asphalt pavement material improvement". International Journal of Latest Research In Engineering and Computing (IJLREC) Vol. 4, Issue 6 , Page No. 7-11. http://www.ijlrec.com/

[10] Lee, S. H. (2020). "Analysis of Mechanical Properties of Asphalt Mix Using Lahar Sand and Crumb Rubber Tire as Replacement for Fine

Aggregates". Retrieved from https://osf.io/2zyvk/

[11] Naha S. Mahaan et al.," An overview of crumb rubber modified bitumen", International journal of the physical science, vol.7 (2), 9 january2012, pp.166-170. https://www.researchgate.net/publication/256839798_An_overview_of_crumb_rubber_modified_asphalt

[12] Nitu H. Deshmukh and D.Y Kshirsagar (2017). Utilization of Rubber Waste in Construction of Flexible Pavement. International Journal of Advance Research, Ideas and Innovations in Technology, 2(7)

[13] PMC Supplies. (n.d.). Dial thermometer for wax melting processes. Retrieved from https://pmcsupplies.com/dial-thermometer-for-wax-melting-processes.html

[14] Pradeep Kumar Gautam, (2018) et al., "Sustainable use of waste in flexible pavement: A review", Construction and Building Materials, Vo. 180, pp 239-253. https://doi.org/10.1016/j.conbuildmat.2018.04.067.

[15] Sharma Pavan Kumar, Saxena Anil Kumar, Arora T.R., 2013, Experimental Study of Flexible Pavement by Using Waste Rubber Tyres, INTERNATIONAL JOURNAL OF ENGINEERING RESEARCH & TECHNOLOGY (IJERT) Volume 02, Issue 08 (August 2013)https://www.ijert.org/experimental-study-of-flexible-pavement-by-using-waste-rubber-tyres

[16] Sharma, Utkarsh and Singh, Sitesh (2018). "Use of Crumb Rubber in Flexible Pavement and Comparison in Strength & Quality". International Journal of Innovative Research in Science, Engineering and Technology.https://www.researchgate.net/publication/325283742_Use_of_Crumb_Rubber_in_Flexible_Pavement_and_Comparison_in_Strength_Quality

[17] Smith, J. D. (2020)."Waste Rubber Tire as an Additive in Asphalt". Retrieved from https://www.academia.edu/41579393/WASTE_RUBBER_TIRE_AS_AN_ADDITIVE_IN_ASPHALT

[18] Walmart.com. (n.d.). Do it rubber mallet. Retrieved from https://www.walmart.com/ip/Do-it-Rubber-Mallet/51694217

[19] Y. Becker, 2001 et al., "Polymer modified asphalt," Vision Tecnologica, vol. 9, no. 1, pp. 39–5. https://www.hindawi.com/journals/tswj/2014/214612/#B57.