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Use of Waste Plastic, Waste Rubber and Fly Ash in Bituminous Mixes

Ghulamsakhi Azizi* and Amit Goel

Department of Civil Engineering, Chandigarh University, Mohali - 140413, Punjab, India; Azizisakhi45@gmail.com, amitgoel.civil@cumail.in

Abstract

Objectives: To explore the use of waste plastic, waste rubber and fly ash as a road construction material. The reduction of bitumen content in the mix by addition of waste plastic and waste rubber is the can help Te focus area which make the mix more economical. **Methods:** The problem of rising costs of road construction materials, combined with the environmental concerns on industrial waste management is driving new research to find a single solution, based on a synergy between the two issues. In this experimental study, waste plastic, waste rubber and fly ash has been used in bituminous mixes and their optimum content percentages are determined. Powder form of waste plastic and waste rubber amount has been used, and the quantity of bitumen has been reduced by that much amount. Standard Marshal Mix design process has been followed. Samples were prepared using various (equal) percentages of waste plastic and waste rubber content (from 4% to 8% by weight of bitumen); with various percentage of bitumen content in mix (from 4% to 8% by weight of total mix). Stone dust (normally 2% by weight of total mix) which is used as a filler, is also replaced (by upto 50%) by fly ash. **Finding:** The statistical analyses like correlation and regression have been done to find the relationship between variables especially the affecting of independent parameters to depended parameters. (Waste plastic was affected to the stability, bitumen was affected to flow value). **Application/Improvements:** The results show that a mix of 5% each of waste plastic and waste rubber (by weight of bitumen) and 4.5% of bitumen in the total mix was found as an optimum percentage by weight of total mix, with 1% fly ash as a filler material to control the flow value.

Keywords: Aggregates, Bitumen, Fly Ash, Marshal Stability Test and Marshall Properties, Waste Plastic, Waste Rubber

1. Introduction

Bituminous mixes used in flexible pavement construction, includes bitumen (used as a binder) and mineral aggregate which are mixed together. Plastic and rubber are very resourceful materials due to the industrial revolution. Several studies have proven the health hazard caused by improper disposal of waste plastic and waste rubber. The usage of waste plastic materials such as carry bags etc. is constantly increasing day by day. Since the polythenes are not biodegradable, the need of the current time is to use the waste plastic in some useful purposes. The possible utilization of waste materials such as waste plastic, waste rubber and fly ash in bituminous mixes can provide a better solution for environmentally sustainable waste management. By using waste materials in road construction, it proves to be environment friendly, economical, gives better strength and durability to the road[1]. The main aim in using the waste plastic on bituminous mix study is to focus on using the waste/ recycled plastic, materials and waste rubber present in bulk which can be used economically and conveniently[2]. The use of fly ash as a filler material can be a better way for related disposal problems. However, by using fly ash, the Marshall Stability value may decrease somewhat, but it increases the resistance of bitumen mixes to moisture damage[3]. Various studies have been reported on the individual or combined use of waste plastic, waste rubber and fly ash in bituminous mixes. Waste plastic and waste

**Author for correspondence*

rubber shredded into small sizes has been used in mix. Several percentages of waste plastic content from 0.25% to 1% by weight of total mix were tried, and 0.75% plastic was found to be the optimum content, with 5.3% bitumen as a binder, with fly ash as a filler[4]. For gradation of aggregate was selected as per IRC: 107–2015 and specification of Ministry of road transport and highway (MORTH, 2001) for 50 mm thick bituminous concrete[5]. The optimum percentage of waste materials with optimum percentage of bitumen content are determined by following the Marshall test procedure to find the Marshall stability parameters (stability, flow value,) and volumetric parameters (voids in mineral aggregates (VMA), voids filled with bitumen (VFB), air content (VA)[6].

Table 1 shows the optimum percentage of waste plastic replacement of bitumen, waste rubber replacement of aggregates, and fly ash replacement of stone dust in bituminous mixes.

2. Materials and Methods

Coarse and fine aggregates are used in the preparation of bituminous mix samples. The gradation of aggregates has been prepared according to IRC: 107–2015 (Table 2). Specific gravity, water absorption, impact value, crushing value and Los angles abrasion value of aggregates are tested according to the Indian standards (Table 3). The specific gravities of coarse and fine aggregates were found to be 2.7 and 2.64, respectively. 50% of stone dust is replaced with fly ash as filler. The specific gravities of the stone dust and fly ash were found to be 2.5 and 2.2, respectively in shown Figure 1.

Table 1. Use of waste materials in bituminous mixes

References	Plastic replacement with bitumen (%)	Rubber replacement with aggregate (%)	Fly ash replacement with stone dust (%)	Optimum waste materials
7	2–10	–	–	5.3%
8	1–5	–	–	4%
9	2–10	0–5	–	10% plastic and 5 % rubber
10	4–8	2–12	–	8 % of plastic and 12% of rubber
		–	–	
11	6–14	–	–	12%
12	5–11	–	–	9%
13	–	1–9	–	5%
14	–		0–100 used as a filler	Stability increase, but flow values tended to decrease

a b c

Figure 1. Waste materials used in the study (a) Fly ash (f class), (b) Shredded Waste rubber (1 mm–75 μm), (c) Shredded Waste plastic (4.75 mm–2.36 mm).

Table 2. Gradation of aggregate according to IRC: 107–2015[16]

Sieve size	Passing %	Select passing %	% Quantity of aggregate
26.5 mm	100	100	
19 mm	85–100	92	8
13.2 mm	63–82	71	21
9.5 mm	52–74	63	8
4.75 mm	39–54	46	17
2.36 mm	28–43	37	9
600 μm	15–27	20	17
300 μm	7–21	18	2
150 μm	5–15	11	7
75 μm	2–8	2	9
Filler 2.36 μm	0–2	2	2

Table 3. Physical properties of aggregates[15]

Property	Test result	Test method	Specification
Water absorption (%)	0.67%	IS:2386 (part-III)	2
Los Angeles test (%)	19.84%	IS:2386 (part-IV)	30
Impact test (%)	23.72%	IS:2386 (part-IV)	24
Crushing test (%)	22.70%	IS:2386 (part-IV)	30

2.1 Bitumen

VG30 grade bitumen has been used as bitumen for preparation of bituminous mixes. The physical properties of bitumen like penetration grade, softening point, and ductility test have been done (Table 4). And also waste plastic and waste rubber Replacement by Bitumen. The Crushed waste plastic according to the size required (4.75 mm–2.36 mm) and waste rubber according to the size required (1 mm–75 μm). And the specific gravity of waste plastic powder and waste rubber powder were found to be 0.47 and 0.509.

2.2 Methodology

The mix design has been considered Stability, Flexibility, Resistant to permanent deformation, Resistant to low-temperature cracking, Durability, Sufficient air voids to prevent bleeding, Workability and economy.

1200 g aggregate, 2% filler by weight of aggregate and various percentages of bitumen with various waste materials by weight of bitumen were selected to find out the optimum percentage of bitumen with waste[18].

Table 4. Physical properties of bitumen (VG30)[17]

Property	Test method	Test result
ductility test	IS:1208–1978	75 cm
penetration test (25°C)	IS:1203–1978	67.666
softening point test	IS:1205–1978	55.5°c
specific gravity	IS:1202–1978	1.06

2.3 Preparation of Mix Specimens

For the preparation of bituminous mixes require quantities of coarse aggregate, fine aggregate, fly ash and stone dust have been taken in an iron pan and kept in an oven at 140°C–175°C for 2hour (IRC-MORTH). And the bitumen also heated 150°C-177°C (IRC-MORTH). Then the waste plastic and waste rubber added to the aggregate and mixed for few minutes. Then Bitumen is added to the mix. And mix process should be continued 12–15 minutes for proper mix; the temperature of mixing should be 120°C–160°C (IRC-MORTH). Prepared mix transferred to a casting mould and compacted at by Marshal Hammer, 75 no. of blows given on each side of the sample then these samples with moulds are kept separately and marked[19].

In this experimental work the preparation of samples have been done in 7 steps.

Step 1: According to literature review and objective the preparation of specimens has been started from 12% waste, and has been done 12% waste with different percentage of bitumen (4% to 8% increment 1%).

Step 2: Select the 10% waste with various percentage of bitumen without 4% bitumen because the result of 4% bitumen was not acceptable.

Step 3: In observed that the optimum percentage of bitumen with waste materials will be between 4.5% to 6% bitumen. And 14% waste with 6%, 5% with increment 0.5% bitumen have been selected.

Step 4: The results of step 3 came acceptable but on 5.5% bitumen had more stability, and it decided to do 5.5% of bitumen with various percentage of waste (12%, 10% and 8%) and also 5% bitumen with 8% waste also has been done.

Step 5: In this stage according to the cost and optimum percentage, the preparation of specimens has been done for 4.5% bitumen with various percentage of waste (12%, 10% and 8%) and the results were satisfied.

Step 6: With consideration of environmental solution by utilization of waste materials, it decided to do 16% of waste with 5.5% and 5% bitumen. But the results were not acceptable.

Step 7: In this stage preparation of specimens has been done for 4.5%, 5% and 5.5% bitumen as conventional mix to compare with use of waste on bituminous mixes.

And also the physical properties of every specimen like unit weight, bulk specific gravity, theoretical Specific gravity and volume of specimen were found (Table 5).

2.4 Marshall Stability Test

Marshall Stability test is very important, significant and standard laboratory test accepted all over world for assessment of bituminous mixes. It has been done to find the marshal properties like stability and flow value for various percentage of bitumen and waste materials. The Marshall Stability (ASTM-D, 1559)[20] has been used for testing of bituminous mixes specimens.

Table 5. Details of materials properties used & related parameters

% Bitumen	% Waste rubber	% Waste plastic	% Course aggregate	% Fine aggregate	% Stone dust	% Fly ash	Volume of specimen (cm^3)	Theoretical specific gravity (Gmm)	Unit weight (gr/cm^3)	Bulk specific gravity (Gmb)
4	6	6	51.796	42.204	1	1	480.467	2.484	2.395	2.310
4.5	0	0	51.520	41.980	2	0	491.144	2.500	2.395	2.517
	4	4	51.520	41.980	1	1	531.183	2.475	2.352	2.307
	5	5	51.520	41.980	1	1	515.168	2.469	2.335	2.410
	6	6	51.520	41.980	1	1	512.498	2.463	2.253	2.239
5	0	0	51.245	41.755	2	0	491.144	2.482	2.496	2.385
	4	4	51.245	41.755	1	1	515.168	2.455	2.539	2.491
	5	5	51.245	41.755	1	1	512.498	2.448	2.493	2.398
	6	6	51.245	41.755	1	1	469.790	2.442	2.419	2.578
	7	7	51.245	41.755	1	1	493.813	2.435	2.429	2.241
	8	8	51.245	41.755	1	1	499.152	2.429	2.306	2.239
5.5	0	0	50.969	41.531	2	0	477.798	2.465	2.462	1.892
	4	4	50.969	41.531	1	1	507.160	2.435	2.468	2.274
	5	5	50.969	41.531	1	1	493.813	2.428	2.439	2.351
	6	6	50.969	41.531	1	1	493.813	2.421	2.305	2.363
	7	7	50.969	41.531	1	1	507.160	2.414	2.302	1.960
	8	8	50.969	41.531	1	1	517.837	2.407	2.239	1.907
6	5	5	50.694	41.306	1	1	496.483	2.408	2.314	2.006
	6	6	50.694	41.306	1	1	491.144	2.401	2.246	1.901
	7	7	50.694	41.306	1	1	464.452	2.393	2.429	2.021
7	5	5	50.143	40.857	1	1	485.806	2.370	2.306	1.903
	6	6	50.143	40.857	1	1	416.405	2.361	2.379	2.299
8	5	5	49.592	40.408	1	1	493.813	2.332	2.405	2.350
	6	6	49.592	40.408	1	1	485.806	2.323	2.399	2.400

3. Results and Discussions

For each trial, were prepared 3 specimens. And the average of 3 specimen results has been reported. The optimum bitumen content criterion was selected to have maximum stability, acceptance flow value, maximum unit weight and acceptance percentage of air voids. And also considered anther criteria according to IS-MORTH for selected optimum bitumen content like Voids filled with bitumen percentage (VFB), water absorbed percentage. And also has been considered the correction factors for Marshall Stability values. And also the all Marshall properties were found (Table 6).

Table 6. Stability, volume of specimen, flow value, %Air voids, %volume of bitumen, %VMA, %VFB and water absorbed

% Bitumen	% Waste plastic	% Waste rubber	Stability (kN)	flow value (mm)	% Air voids (AV)	% Volume of bitumen	%VMA	%VFB	%Water absorbed
4	6	6	7.913	2.866	9.894	3.753	13.648	27.501	0.690
4.5	0	0	17.773	2.333	3.997	4.441	8.438	52.628	0.743
	4	4	14.538	2.800	22.941	5.141	28.081	18.306	14.194
	5	5	18.089	2.767	2.371	4.746	7.117	66.686	1.887
	6	6	16.196	3.000	22.810	4.933	27.743	17.781	13.106
5	0	0	17.424	2.833	3.346	5.813	9.160	63.466	–0.661
	4	4	15.144	3.233	19.311	5.036	24.346	20.683	14.537
	5	5	16.091	2.833	2.061	5.232	7.293	71.740	1.020
	6	6	15.018	3.200	6.394	4.523	10.917	41.432	0.972
	7	7	11.922	2.367	22.295	5.339	27.634	19.321	6.729
	8	8	14.328	2.900	21.633	5.185	26.817	19.334	13.561
5.5	0	0	15.825	3.033	3.098	5.369	8.467	63.413	–1.261
	4	4	13.562	3.400	19.925	6.049	25.974	23.289	13.667
	5	5	15.934	3.233	3.175	5.711	8.885	64.268	2.090
	6	6	13.756	3.233	2.399	5.584	7.983	69.948	1.916
	7	7	8.312	2.533	7.264	4.926	12.189	40.410	9.536
	8	8	9.886	2.900	16.042	5.330	21.372	24.939	11.464
6	5	5	11.484	2.600	–0.088	5.182	5.094	101.736	–6.753
	6	6	13.412	3.567	3.912	5.295	9.207	57.508	0.533
	7	7	10.387	1.667	6.379	5.328	11.707	45.511	9.007
7	5	5	9.858	2.733	–5.112	5.762	0.650	885.902	–7.133
	6	6	12.469	3.833	2.640	6.944	9.584	72.458	0.217
8	5	5	7.336	4.933	–2.278	6.774	4.495	150.684	–3.836
	6	6	12.151	3.233	0.520	6.838	7.358	92.931	0.000

In this experimental work has been done various percentage bitumen with various percentage of waste plastic and waste rubber to find the optimum percentage of waste material on bituminous mixes. But according to the cost and acceptance results of 4.5% to 5.5% with 0.5% increment bitumen. The Marshall Properties graphs have been plotted on 4.5%, 5% and 5.5% of bitumen with 0%, 8%, 10% and 12% of waste plastic and waste rubber. And also 50% of fly ash as a filler considered.

As shown in Figure 2(a) stability increases with bitumen content up to 4.5% on conventional mix. And on use of all percentage waste plastic, waste rubber and fly ash on bituminous mix stability increases with bitumen up to 4.5%. And especially 5% waste plastic and 5% waste rubber stability increases up to 4.5%. Figure-B shows that the flow values increases large variance between trials with bitumen contents in conventional mix. But in use of waste plastic, waste rubber and fly ash on bituminous

Fig A

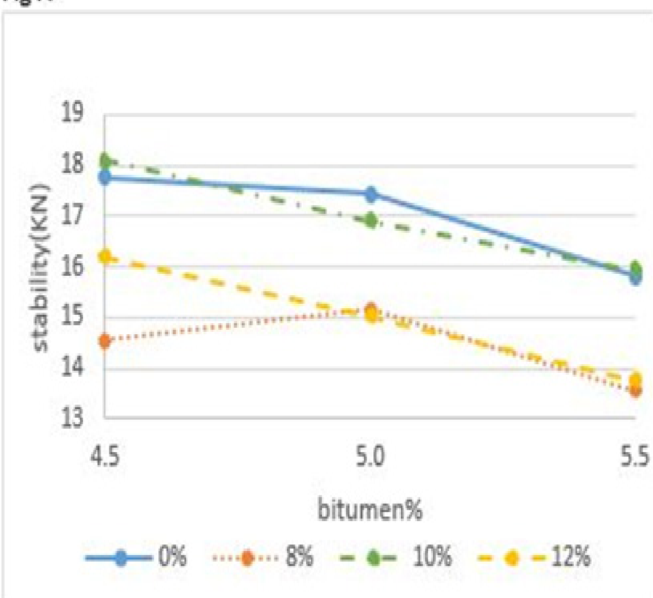


Fig D

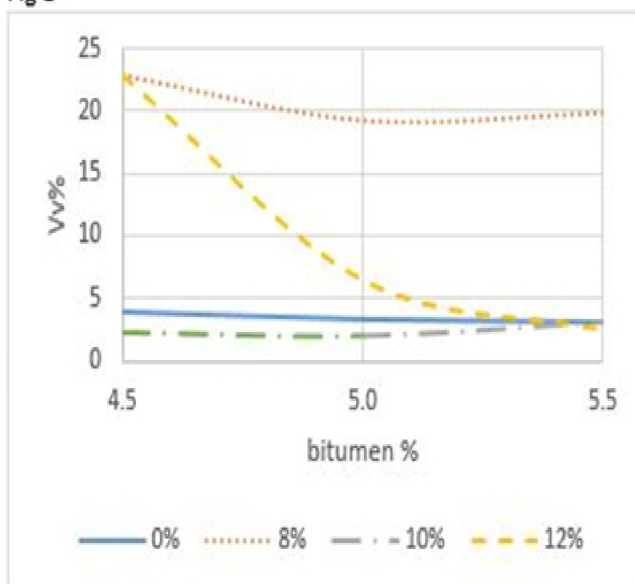


Fig B

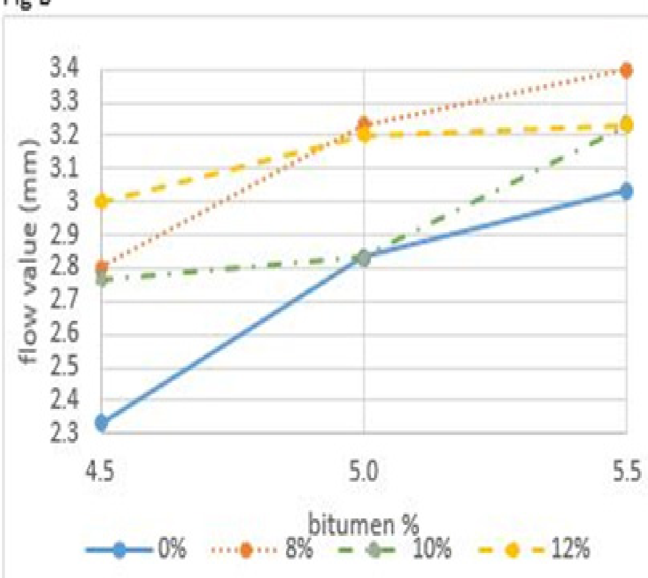
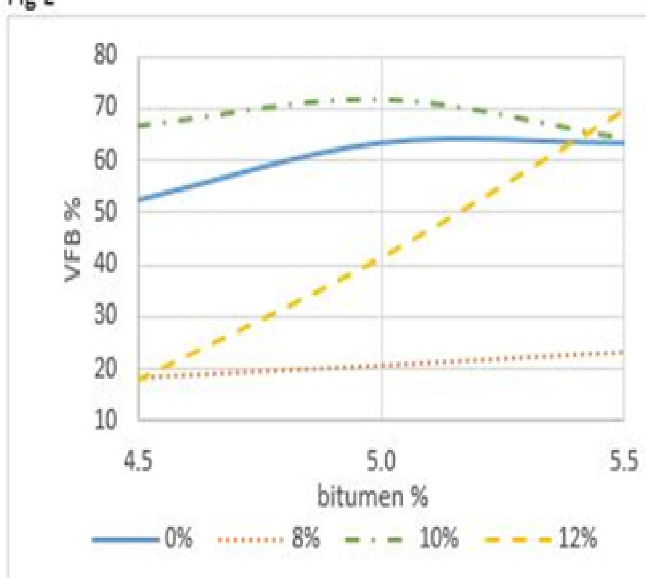


Fig E



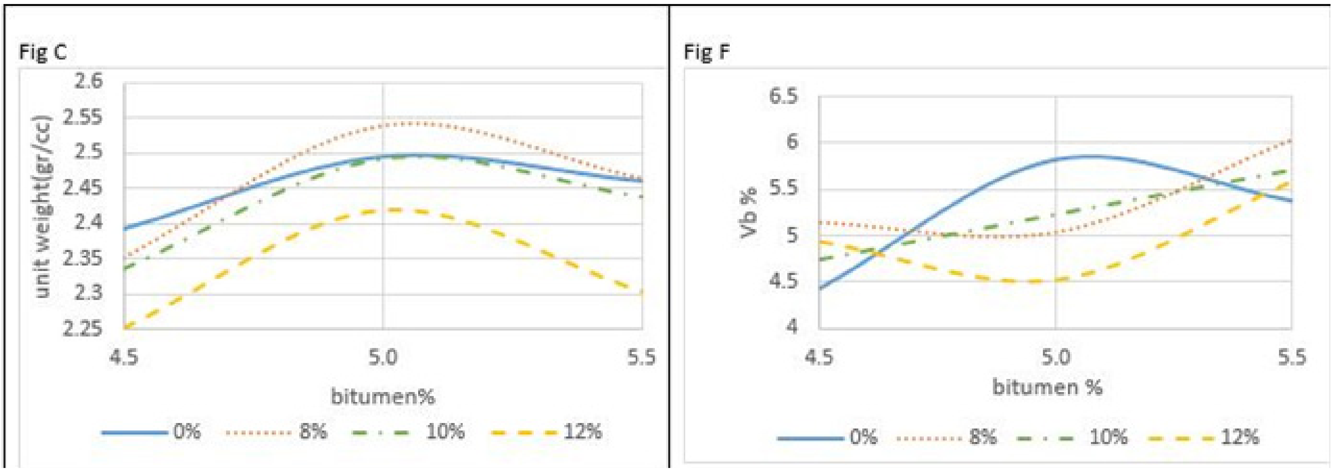


Figure 2. Comprising various percentage waste plastic, waste rubber and fly ash with conventional mix **(A)** Variation of stability with bitumen content for mixes with various percentage of waste. **(B)** Variation of flow value with bitumen content for mixes with various percentage of waste. **(C)** Variation of unit weight with bitumen content for mixes with various percentage of waste. **(D)** Variation of air voids with bitumen content for mixes with various percentage of waste. **(E)** Variation of Voids filled with bitumen with bitumen content for mixes with various percentage of waste. **(F)** Variation of volume of bitumen with bitumen content for mixes with various percentage of waste.

mixes flow values also increases small variance between trials with bitumen contents, especially 5% waste plastic, 5% waste rubber and 50% fly ash as a filler control the flow value as normal. And it is seen from Figure-C unite weight increases with bitumen contents up to 5%. Especially on 4% waste plastic and 4% waste rubber with 5% bitumen. It is seen from Figure-D air voids decreases with bitumen contents. But the decreasing of flow values on 5% waste plastic and 5% waste rubber is normal than another's trials.

As shown in Figure-E voids filled with bitumen increases with bitumen contents on conventional mixes. And in use of waste plastic, waste rubber and fly ash in bituminous mixes voids filled with bitumen increase with bitumen contents. But on 5% waste plastic and 5% waste rubber voids filled with bitumen increases up to 5% bitumen content and then decreases. It is seen from Figure-F volume of bitumen in 5% waste plastic and 5% waste rubber normal increases with bitumen contents.

4. Statistical Analysis

4.1 Correlation

The data includes 24 laboratory experimental observations. The database includes information about course aggregate (CA), fine aggregate (FA), stone dust (SD), fly ash (F), bitumen (B), waste materials (WM) (waste plastic and waste rubber), unit weight of specimens, air voids (AV), volume of bitumen (Vb), Voids filled with bitumen (VFB), Voids in mineral aggregate (VMA), water Absorbed (WA), stability value (KN), flow value (mm). Some of experimental results have been presented in **Table 5** and some of experimental results have been presented in **Table 6.**

Table 7. Summary of statistical value of parameters

Properties	CA%	FA%	SD%	%F	WM%	B%	Unit weight (g/cc)	AV%	Vb%	VFB%	WA%	Stability (□N)	Flow value (mm)
mean	50.94	41.5	1.1	0.9	10.08	5.54	2.37	8.12	5.38	87.99	4	13.28	3
S.D	0.580	0.47	0.3	0.3	4.47	1.05	0.08	8.85	0.74	172.93	6.74	3.14	0.60
C.O.V	0.011	0.01	0.3	0.4	0.44	0.19	0.03	1.09	0.13	1.96	1.68	0.24	0.20

The mean, standard deviation (S.D) and coefficient of variation (C.O.V) of data set are showing in **Table 7**. The coefficient of variation is showing the variability of output parameters measurement. The successful usage of this method depends upon the exploration of appropriate input parameters. CA, FA, filler, bitumen and waste plastic & rubber are important input parameters. Stability, flow value, air voids are important output parameters. The selection of input parameters are based on the correlation coefficient (R) with output parameters. The correlation coefficient value is **$-1 \le R \le 1$.** The **(+)** value is showing positive correlation, **(–)** value is showing negative correlation and **(0)** value is showing no correlation. The absolute value of correlation coefficient close to value 1, it is showing stronger correlation between tested variable. While close to (0) it is showing poor correlation between tested variable[21].

Approximately all parameters were affected the stability, specially course aggregate, fine aggregate, filler, waste materials, bitumen content and unite weight. And also almost parameters were affected the flow value specially course aggregate, fine aggregate, filler and bitumen. Course aggregate, fine aggregate, waste materials and bitumen were also affected the air voids. And air voids parameter was affected the water absorbed. With consideration of correlation coefficient value, to find the relationship between variable. It means to predict the effect of input parameters to output parameters.

4.2 Regression

Correlation and regression both are showing the relationship between variables in shown Table 8. But correlation is showing the affecting of between two variables, we cannot say that variable is the cause and other is effect. And by Regression may able to predict the value of one on the basis of another. And also showing the close relationship between two variables and estimate the confidence of affecting. This experimental study has two types' parameters, one is independent like course aggregate (CA), fine aggregate (FA), filler (F), bitumen (B) and waste materials and another is dependent like stability, flow value and …The regression has been done to predict the affecting of independent parameters on dependent parameters, and also estimate the confidence percentage of affecting. In this study has been found the close relationship and significant of all independent parameters on stability parameter and flow value and also estimated the percentage confidence of affecting.

As shown in Table 9, without waste plastic the p-value is not significant. That's way the Regression for stability on waste materials has been done. The result show with 99.1% confident and 0.9% significant waste plastic was affected to the stability Table 10.

As shown in Table 11, the p-value of course aggregate and bitumen content are significant but fine aggregate and waste materials are not significant. That's way the regression for flow value on course aggregate and bitumen have been done.

Table 8. Correlation between variables [showing relationship between input (materials used) and output (results) parameters]

	CA%	FA	Stone dust%	Fly ash %	WM%	B%	Air voids %	WA%	Stability (KN)	Flow value (mm)
CA%	1									
FA	**1**	1								
stone dust%	**–0.78**	**–0.78**	1							
fly ash %	**0.78**	**0.78**	–1	1						
WM%	–0.17	–0.17	0.11	–0.11	1					
B%	**–1**	**–1**	**0.78**	**–0.78**	0.17	1				
Air voids %	**0.54**	**0.54**	**–0.34**	**0.34**	0.24	**–0.54**	1			
WA%	**0.44**	**0.44**	**–0.30**	**0.30**	**0.30**	**–0.44**	**0.89**	1		
stability(KN)	**0.48**	**0.48**	**–0.32**	**0.32**	**–0.54**	**–0.48**	0.11	0.11	1	
flow value(mm)	**–0.50**	**–0.50**	**0.64**	**–0.64**	0.00	**0.50**	–0.19	–0.21	–0.15	1

Note: bold coefficient are significant.

As shown in Table 12, the p-value of course aggregate is not significant and the p-value of bitumen is significant. That's way the regression for flow value on bitumen has been done. The result shows with 98.7% confident and 1.3% significant bitumen was affected to flow value (Tables 13–14).

Table 9. Regression for stability on course aggregate, fine aggregate, bitumen and waste materials

	Coefficients	*P-value*
Intercept	21.429	0.049
CA%	−1.063	0.733
FA%	1.173	0.453
WM%	−0.328	**0.023**
Bitumen %	−1.186	0.714

Note: bold coefficient is significant.

Table 10. Regression for stability on waste materials

	Coefficients	*P-value*
Intercept	16.032	0.000
WM%	−0.378	**0.009**

Note: bold coefficient is significant.

Table 11. Regression for flow value on course aggregate, fine aggregate, bitumen and waste materials

	Coefficients	*P-value*
Intercept	−2.416	0.214
CA%	−1.286	**0.035**
FA%	0.455	0.123
Bitumen %	1.536	**0.017**
WM%	−0.001	0.983

Note: bold coefficient are significant

Table 12. Regression for flow value on course aggregate and bitumen

	Coefficients	*P-value*
Intercept	−1.204	0.485
CA%	−0.585	0.115
Bitumen %	1.163	**0.044**

Note: bold coefficient is significant.

Table 13. Regression for flow value on bitumen

	Coefficients	*P-value*
Intercept	1.413	0.028
Bitumen %	0.287	**0.013**

Note: bold coefficient is significant

5. Conclusion

In this experimental study, the use of waste plastic and waste rubber were used as a binder replacement by bitumen and use of fly ash as a filler by replacement of stone dust on bituminous mixes. Marshall Stability test has been done to find out the optimum Marshall Properties, compare with conventional mixes, considered the cost of road materials and environmental problems solving by utilization of waste plastic and waste rubber. Fly ash has been used to control the flow value parameters.

- Optimum Marshall Properties are observed by the use of waste plastic and waste rubber on bituminous mixes with consideration of optimum bitumen content criteria. The results of the all Marshall properties use of 5% waste plastic and 5% waste rubber as a partial replacement by bitumen with 4.5% bitumen content are optimum percentage according to IS:SP:98–2013. [On conventional mixes 4.5% bitumen content satisfy than another's bitumen contents]. 4.5% bitumen content on modified mix Stability and air voids increases than conventional mix. And also voids filled with bitumen percentage satisfied than conventional mix.

Table 14. Cost Analysis of road materials

Bitumen %	Waste materials %	(₹) Bitumen price	(₹) Waste plastic price	(₹) Waste rubber price	(₹) Conventional mix price	(₹) Bitumen with waste price	% Change
4.5%	10%	25/kg	11/kg	12/kg	4.05	3.813	5.4%

- 50% fly ash as a filler was used to control the flow value parameter than conventional mix.
- By utilization of waste plastic and waste rubber on bituminous mixes to prevent the increasing of waste materials and solve the environmental problems.
- With consideration of road materials cost. By usage of waste plastic and waste rubber as a road material to compare with conventional mixes. Especially optimum percentage of bituminous mix. The price of materials.

6. Future Scope

For usage of waste materials in bituminous mixes should consider the following parameters:

- Check physical and chemical properties of all road materials especially waste materials mixed with bitumen.
- Use of waste plastic and waste rubber together with partial replacement of bitumen as a binder.
- Stability comparison of modified and conventional bituminous mixes.
- Predication the Marshall parameters Using Artificial Intelligence Techniques.

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