Effect of Crumb Rubber and Fly Ash on the Mechanical Properties of Semi Rigid Pavement

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Abstract— Mostly used flexible pavements in Pakistan have major problems, i.e., rutting, surface wear and cracks. Therefore, enhancement in its properties is necessary. The Semi-rigid pavement is a composite pavement that forms the combination of flexible and rigid pavement materials, it has an open-graded asphalt concrete structure consists of 25-30% air voids which fills with portland cement grout. For the improvement of properties and cost of a semi-rigid pavement, some new materials like crumb rubber and fly ash are used in flexible portion and rigid portion respectively are introduced to overcome the environmental impacts of waste and the mechanical properties of SRP is determined. This study is divided in three main parts, while making f samples. Firstly, replacement crumb rubber-CR (waste) 5%, 10% & 15% with aggregates mix while fly ash-FA (waste) has no replacement with cement. Secondly, no replacement of CR has been made with aggregate mix and FA replaced with cement as 5%, 10% & 15%. Third, 5%, 10% & 15% replacement of CR and FA with aggregate mix and cement respectively. After curing, the compressive strength results achieved are significantly great as compared to normal semi-rigid pavement samples. The samples showed great initial strength after 3 days curing which is 17.11% more than normal SRP samples. The maximum results among curing days and percentage replacement of CR & FA achieved 9.34 MPa after 28 days curing at 15% CR & FA replacement with aggregate mix & cement respectively.

Index Terms— Semi rigid pavement (SRP), Open-graded asphalt concrete (OGAC), Optimum asphalt content (OAC), Crumb rubber (CR), Fly ash (FA), Grout & Compressive strength.

1 Introduction

Semi-Rigid Pavement is a composite pavement that forms the combination of flexible and rigid pavement materials in the same layer. An open-graded asphalt concrete mixture containing 25%-35% air voids which are filled with a resin modified portland cement grout, is generally describe the SRP layer. The SRP has two portions, one is open graded asphalt concrete (flexible) and other is grout material (rigid). After combination, the SRP has high strength properties to bear substantial traffic loading conditions, has satisfactory skid resistance, durable with fast construction, impermeable and has easy maintenance). However, in period of globalization the focus has not only been given to development rather the sustainable development.

In flexible portion of SRP, the best way to recycle a specific portion of this waste is to use it in road and other infrastructure constructions. Increasing in the amount of waste tires disposal is a serious problem leading to environmental pollution. The utilization of waste crumb rubber as a modifier material in the asphalt has been considerable for researchers over the recent four decades. Crumb rubber obtained from shredding of those scrap tires has been proven to enhance the properties of plain bitumen since the 1840s.

The research examined an impact of waste rubber tire (5 to 15% with 2.5% interval), in powder form as mineral filler on the mechanical properties of hot blend asphalt. From results of marshall tests, asphalt wearing coarse waste tire rubber discovered optimum at 10% filler content in the hot blend blacktop [1].

After utilization of crumb rubber in the open graded portion maintaining 25%-30% in its skeleton, the portland cement grout (rigid portion of SRP) can be poured in it and due to economical purpose portland cement can be replaced materials containing similar properties with cement like fly ash.

The study showed that both workability and compressive strength increased with replacement of Fly ash. The fieldwork use is easy, quick installation and low costs are required for this type of pavement. Therefore, it is a preferable solution due to the low installation costs and shorter construction process compared to conventional pavement. It also offers a solution for pavement area that demands higher strength, durability, and chemical resistance [2].

The research objectives were to investigate the effect of using crumb rubber, fly ash & use of both on the mechanical properties of semi rigid pavement.

The scope of this research was that the semi rigid pavement needs attention for the improvement and as a matter of fact there is always a need of further improvement of economy in any topic of interest. For the improvement of properties and cost of a semi-rigid pavement, a new material Fly Ash is introduced in rigid pavement portion and crumb rubber is used in

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flexible pavement portion to overcome the environmental impacts of waste and the mechanical properties of SRP is determined.

2 Literature Review

Author [3] discussed construction of laying of surface layer for Cement Grouted Bituminous Mix (CGBM), preferably over an existing bituminous pavement. CGBM is based on the concept of preparing a coarse aggregate skeleton structure which is then filled with cementitious grout material. Almost single graded bituminous mix (having voids more than 25% which is more than the voids in traditional dense graded bituminous mixes) is paved and grouted with cement grout.

The study [4&5] investigated the engineering properties of resin modified pavement and concluded that flexural strength of RMP has 40% to 60% more as compared to traditional PCC pavement and compressive strength of RMP has 10% to 25% more as compared to traditional PCC pavement.

The report [6] published in detail in which determined the laboratory evaluations for the open-graded asphalt mixture, cement slurry grout mix designs. For evaluation of open-graded asphalt mixture, different aggregate stockpiles and sieve analysis tests conducted on these, after that JMF (Job Mix Formula) generated maintaining in that 25%-30% air voids then optimum asphalt content found out 4.1% (ranging from 3.7 to 4.5%). For cement slurry grout mix, those materials included a silica sand, fly ash, Type I portland cement, water, and the cross-polymer resin additive.

Author [7] prepared semi rigid mixtures specimens by grouting cement mortar into an open graded bituminous mix. From results, the air voids 20-30% and filling rate of Semi Rigid mixtures specimens were greatly influenced by the flowability of cement grout within 12 seconds.

Research [8] evaluated effect of fluidity of cementitious grout on mechanical properties of semirigid pavement. Asphalt porous skeletons were prepared with porosity ranges 18-22%.

The results of study [9] of open graded asphalt recommended the voids ratio should be 25% to 30%. And from the results of grouted pavement mixes, compressive strength higher achieved at 95% OPC with 5% silica fume replacement with addition of 2% SP at 0.30 w/c.

Research [10] conducted program to evaluate Semi-Flexible Pavement (SFP) as an alternative to ultra-thin white topping (UTW) and by laboratory tests semi-flexible pavement samples possessed enough strength and durability to be considered as an option to ultra-thin white topping. The SFP system was promoted as providing the best of both conventional paving systems.

Research [11] showed influence of the scrap tire on the properties of CRMB mixes was examined by looking at consistency with a Brookfield viscometer and 15% CR concentration in the mix met all the consistency prerequisites.

The study [12] showed for mix design, marshal stability test was conducted and at last, different sizes of crumb rubber (0.3 mm-0.15 mm) gave the highest value of stability 1597.64 kg.

Author in [13] showed the best performance of crumb rubber powder at higher temperatures was analyzed at 10%.

The study [14] investigated to determine the compressive strength of porous concrete by replacing the cement with Fly ash. The optimum results obtained at 30% replacement of Fly ash in porous concrete.

The study [15] showed the use of Fly ash in rigid pavement. Cement and sand were replaced with Fly ash to an extent of 10 to 30% and 5 to 15% respectively. Then compressive and flexural strength tests were conducted on specimens which were cured at 7, 14 and 28 days. The optimum results were obtained at 25% replacement of cement by Fly ash.

3 Materials

To produce the SRP laboratory samples, each material is below described:

3.1 Aggregates

In this research work, vibratory screening deck was used to separate the aggregates into individual sieve sizes. To separate aggregates into the sieve sizes as 12.50 mm, 9.50 mm, 4.75 mm, 2.36 mm, 1.18 mm, and 300 μm, the screening deck has contained sufficient screens.

3.2 Bitumen

The bitumen grade used in this research was 60/70 for production of open-graded asphalt concrete mixtures for all SRP samples.

3.3 Crumb Rubber

CR was prepared or got by mechanical method (cutting and making into smaller pieces i.e., shredding) then sieved and appropriate size of 2.36 mm (passed from 2.36 mm sieve and retained at 0.075 mm sieve) was taken.

3.4 Grout Material

The OGAC (Open Graded Asphalt Concrete) must be intruded with highly workable grout, for this objective two different grouts were selected (i.e., OPC and Fly Ash). The constituents of the grouts are cement, fly Ash (passed from 325 microns sieve), sand and water.

4 Sample Preparation

Laboratory SRP & MSRP (Modified SRP) samples were generally produced in 101.6 mm diameter by 63.5 mm thick cylinders size. The samples of SRP were made with aggregates, bitumen, and grout while the MSRP samples were produced with the same materials including CR (replaced with 1.18 mm sieve size aggregates as 5%, 10% & 15%) and FA (replaced with cement in grout as 5%, 10 & 15%) as an individual and combination of each (CR-FA 5%, 10% & 15%). For determining the optimum values of aggregate stockpiles and asphalt content a mix design was prepared. The optimum formula in this case provides a compacted OGAC mixture that has an air void very close to 30%.

In the initial stage of OGAC mix design, the optimum blending formula of each aggregate stockpile described in table 1

Table 1 Optimum Blending Formula for OGAC Aggregates **(Gary Lee Anderton, 2000)**

Stockpile	**12.50 mm**	**9.50 mm**	**4.75 mm**	**2.36 mm**	**1.18 mm**	**300 µm**
Ap.Sp. Gr (Gsb)	2.73	2.73	2.74	2.72	2.69	2.77
% **By weight**	**40**	**10**	**35**	**5**	**4**	**6**
	Passing Percentage					
Sieve Sizes	**Specified Range**			**Optimum Values**		
19.0 mm	100.00			100.00		
12.50 mm	54-76.00			62.80		
9.50 mm	38-60.00			51.50		
4.75 mm	10-26.00			17.60		
2.36 mm	8.00-16.00			11.10		
1.18 mm	--			7.30		
600 µm	4.00-10.00			6.60		
300 µm	--			2.40		
150 µm	--			1.20		
75 µm	1.00-3.00			1.10		

Now, the apparent specific gravity of the combined aggregates representing the optimum blending formula was then calculated as follows (Asphalt Institute 1989):

G_{sb} = apparent specific gravity of aggregate blend

$$Gsb = \frac{100}{P1/G1 + P2/G2 + \ldots + Pn/Gn} = \frac{100}{\frac{40}{2.73} + \frac{100}{2.73} + \frac{35}{2.72} + \frac{5}{2.71} + \frac{4}{2.67} + \frac{6}{2.62}}$$

Gsb = 2.716

The next step was to find the optimum asphalt content. This was achieved by using the equation given below, (Roffe, Jean C, 1989b):

Optimum Asphalt Content (OAC) = $3.25\ \alpha \sum^{0.2}$

where,

α = 2.65/Gsb = 2.65/2.716 = 0.976

$\sum$= conventional sp. surface area = 0.21G + 5.4S + 7.2s + 135f

G = % of material retained on 4.75-mm sieve = 0.824

S (capital alphabet) = % of material passing 4.75-mm sieve and retained on 600 microns sieve = 0.110

S (small alphabet) = % of material passing 600-um sieve and retained on 75-um sieve = 0.055

f= % of material passing 75-um sieve = 0.0110

$\sum$ = 2.648

OAC = $3.25\ \alpha \sum^{0.2} = 3.25\ (0.976)\ (2.648)^{0.2}$

OAC = 3.9%

In the last step, a 1200 grams batch of aggregates meeting the blending formula was prepared for each of the fifteen Marshal samples to be produced. Then each individual batch of aggregate was dried and heated at 145 ^{o}C and the asphalt cement was poured in the samples, which was preheated to 135 ^{o}C. The warmed-up aggregates and proportionate amount of heated asphalt cement to create the proper asphalt content, which were combined and mixed in a mechanical mixer for 15 to 30 seconds approximately. For coating all the aggregates with asphalt, 15-20 sec were enough. Immediately after mixing, the mixture was placed in a 101.6 mm marshal dia mold and compacted with 25 blows from a 4.5 kg hammer on one side of the sample. The pavement samples' flexible portion were made in two portions. The first category samples were made normally (conventional) SRP, while the other samples were made the replacement of crumb rubber with size of aggregates (passing from 2.36 mm and retained on 1.18 mm size). Then the grout was intruded into asphalt skeleton to fill the pores which were left while preparing flexible portion of the skeleton of samples. This portion is also known as rigid pavement of SRP. This portion also contained two portions; one contained normal portland cement grout, while the other made replacement of fly ash with cement. A suitable grout mix design is one that meets the batching percentage and viscosity requirements. Immediately after mixing when measured with the Marsh flow cone, the viscosity requirement is 8 to 10 seconds. Therefore, twenty samples were prepared; ten samples with combination of cement and sand (dry ingredients) whereas, other ten samples were with cement, fly ash and sand (dry ingredients) by fixing their proportions and changing w/c amount with specified limits (2 samples per w/c amount) mentioned in table 2 & 3.

Table 2 Portland Cement Grout Mixture Results

Blend	**Cement (%)**	**Sand (%)**	**Water (%)**	**Flow Time (seconds)**
1	55	18	24	17
2	55	18	25	13
3	55	18	26	11
4	**55**	**18**	**27**	**9.5**
5	55	18	28	7

Table 3 Portland Cement plus Fly Ash Grout Mixture Results

Blend	Cement (%)	Fly Ash (%)	Sand (%)	Water (%)	Flow Time (seconds)
1	35	20	18	24	16.5
2	35	20	18	25	12
3	35	20	18	26	11
4	**35**	**20**	**18**	**27**	**9**
5	35	20	18	28	6.5

Then grout was continually poured onto the top of each sample until it was fully-saturated, then freshly grouted samples air cured in the lab for several hours until the surface bleed water had evaporated. After that the samples remained in the water tank for 3, 7 & 28 days before testing.

5 Results & Disscussion

The most common strength test conducted on pavement materials is "Compressive strength". While conducting the test, this test is easy as compared to other tests and other properties can also be determined in terms of compressive strength. Compressive strength test was conducted on SRP and MSRP samples to establish baseline values for comparisons between them.

Table 4 Comparison between SRP and Modified SRP Compressive Strength Test Results having CR 5%& FA 0% for different days

Curing Time (Days)	Av. Stress of SRP (MPa)	Av. Stress of MSRP (MPa)	Percentage (%) w.r.t SRP	Remarks
3	5.20	5.41	4.04	Increase
7	8.78	8.82	0.45	Increase
28	9.03	9.10	0.77	Increase

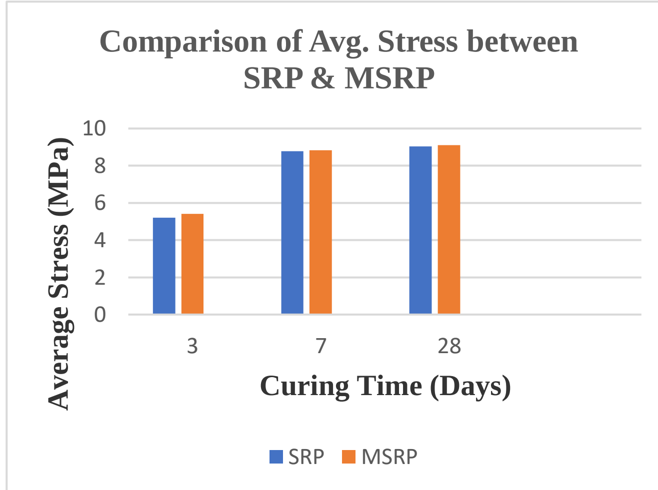


Table 5 Comparison between SRP and Modified SRP Compressive Strength Test Results having CR 10%& FA 0% for different days

Curing Time (Days)	Av. Stress of SRP (MPa)	Av. Stress of MSRP (MPa)	Percentage (%) w.r.t SRP	Remarks
3	5.20	5.72	10.0	Increase
7	8.78	8.85	0.80	Increase
28	9.03	9.15	1.33	Increase

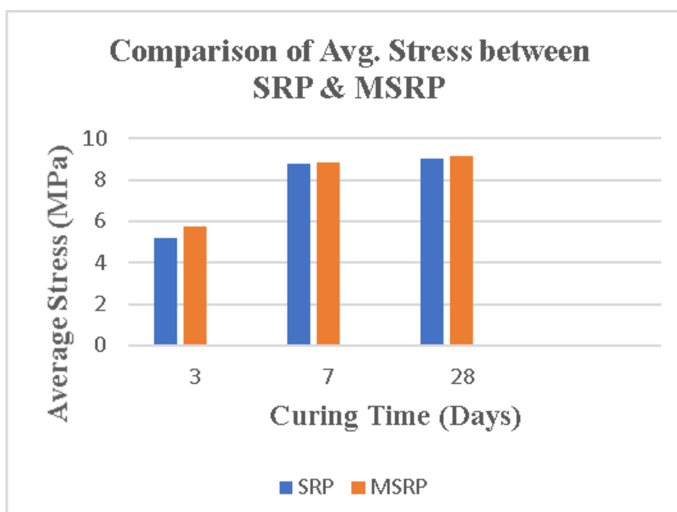


Table 6 Comparison between SRP and Modified SRP Compressive Strength Test Results having CR 15%& FA 0% for different days

Curing Time (Days)	Av. Stress of SRP (MPa)	Av. Stress of MSRP (MPa)	Percentage (%) w.r.t SRP	Remarks
3	5.20	5.81	11.73	Increase
7	8.78	8.90	1.37	Increase
28	9.03	9.18	1.66	Increase

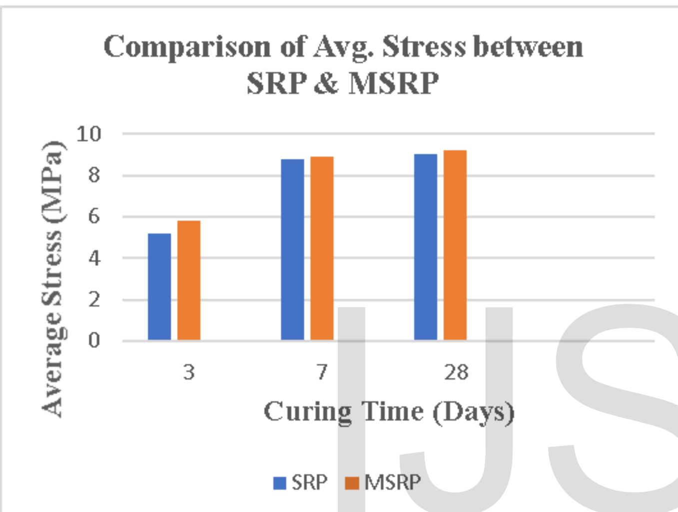


Table 7 Comparison between SRP and Modified SRP Compressive Strength Test Results having CR 0%& FA 5% for different days

Curing Time (Days)	Av. Stress of SRP (MPa)	Av. Stress of MSRP (MPa)	Percentage (%) w.r.t SRP	Remarks
3	5.20	5.73	10.19	Increase
7	8.78	8.88	1.14	Increase
28	9.03	9.14	1.22	Increase

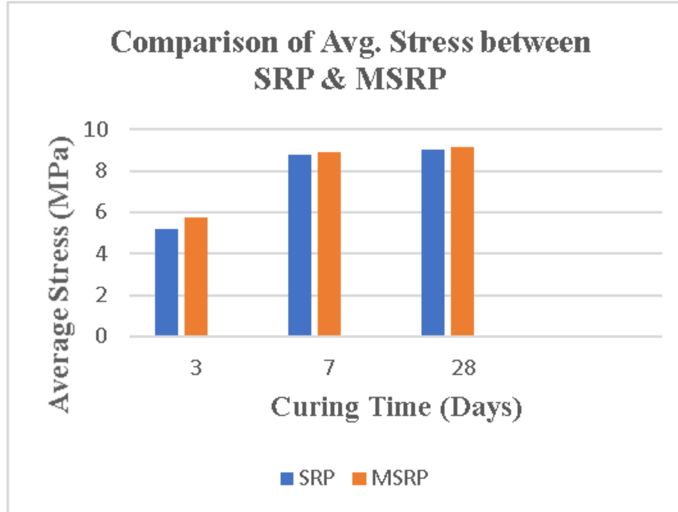


Table 8 Comparison between SRP and Modified SRP Compressive Strength Test Results having CR 0%& FA 10% for different days

Curing Time (Days)	Av. Stress of SRP (MPa)	Av. Stress of MSRP (MPa)	Percentage (%) w.r.t SRP	Remarks
3	5.20	5.95	14.42	Increase
7	8.78	8.98	2.28	Increase
28	9.03	9.22	2.10	Increase

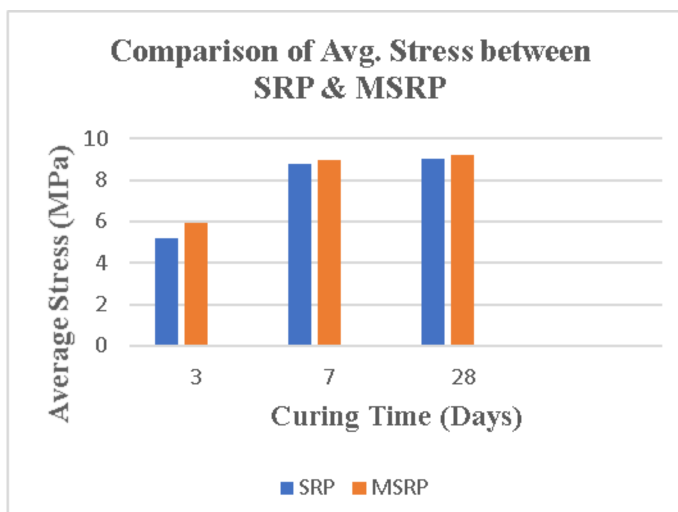


Table 9 Comparison between SRP and Modified SRP Compressive Strength Test Results having CR 0%& FA 15% for different days

Curing Time (Days)	Av. Stress of SRP (MPa)	Av. Stress of MSRP (MPa)	Percentage (%) w.r.t SRP	Remarks
3	5.20	6.07	22.45	Increase
7	8.78	9.02	2.73	Increase
28	9.03	9.29	2.88	Increase

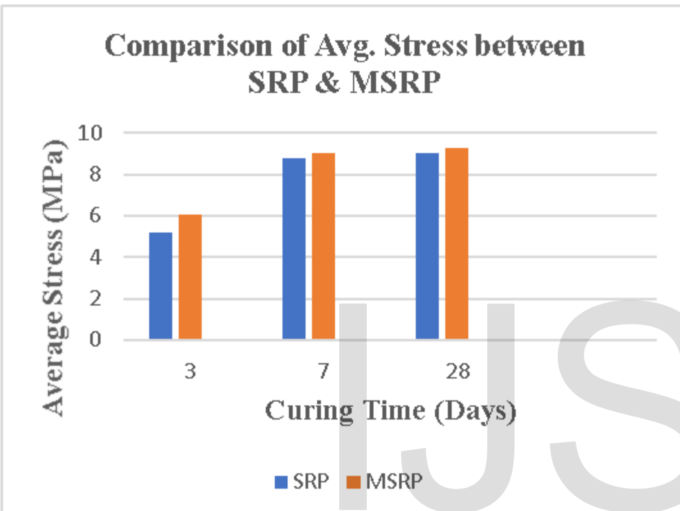


Table 10 Comparison between SRP and Modified SRP Compressive Strength Test Results having CR 5%& FA 5% for different days

Curing Time (Days)	Av. Stress of SRP (MPa)	Av. Stress of MSRP (MPa)	Percentage (%) w.r.t SRP	Remarks
3	5.20	5.79	11.35	Increase
7	8.78	8.96	2.05	Increase
28	9.03	9.20	1.88	Increase

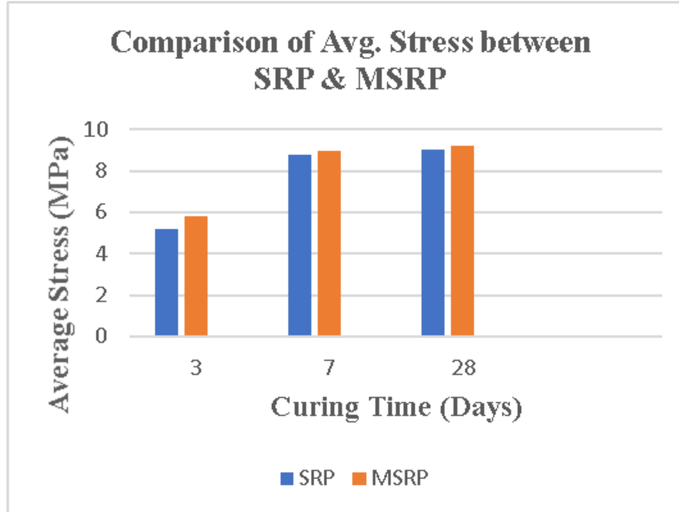


Table 11 Comparison between SRP and Modified SRP Compressive Strength Test Results having CR 10%& FA 10% for different days

Curing Time (Days)	Av. Stress of SRP (MPa)	Av. Stress of MSRP (MPa)	Percentage (%) w.r.t SRP	Remarks
3	5.20	6.01	15.58	Increase
7	8.78	9.03	2.85	Increase
28	9.03	9.25	2.44	Increase

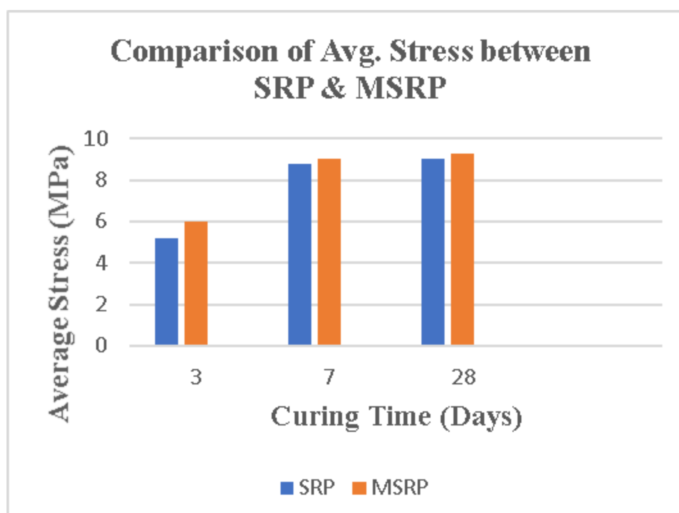


Table 12 Comparison between SRP and Modified SRP Compressive Strength Test Results having CR 15%& FA 15% for different days

Curing Time (Days)	Av. Stress of SRP (MPa)	Av. Stress of MSRP (MPa)	Percentage (%) w.r.t SRP	Remarks
3	5.20	6.09	17.11	Increase
7	8.78	9.14	4.10	Increase
28	9.03	9.34	3.43	Increase

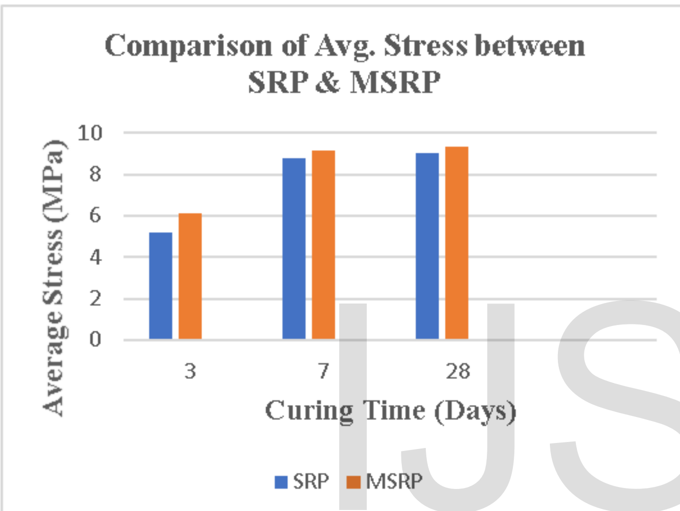


Table 13 Compressive Strength Test Results of CR & FA having different % & comparison among them for 3 curing days

Curing Time (Days)	CR %	FA %	Av. Stress (MPa)	Percentage (%)	Remarks
3	0	0	5.20	--	--
3	5	0	5.41	4.04	Increase
3	0	5	5.73	5.91	Increase
3	5	5	5.79	1.05	Increase
3	0	0	5.20	--	--
3	10	0	5.72	10.0	Increase
3	0	10	5.95	9.98	Increase
3	10	10	6.01	1.00	Increase
3	0	0	5.20	--	--
3	15	0	5.81	11.73	Increase
3	0	15	6.07	4.47	Increase
3	15	15	6.09	0.33	Increase

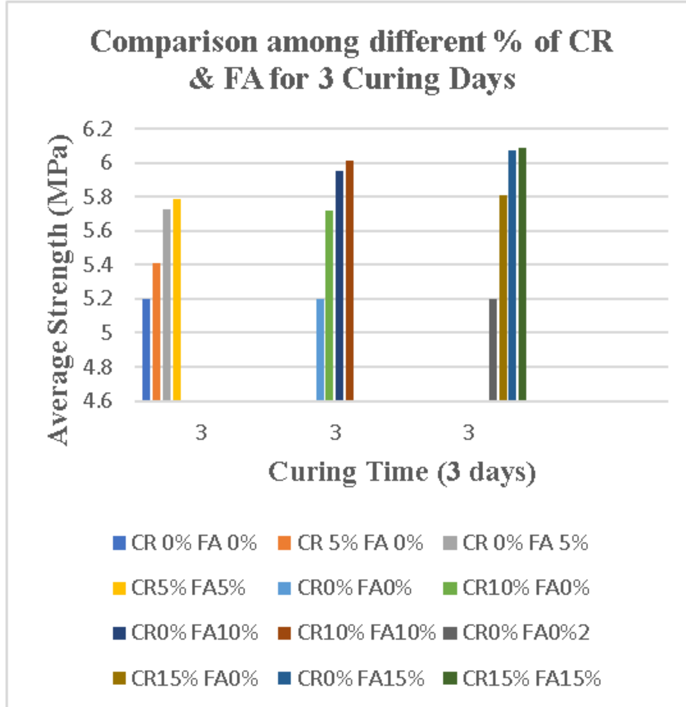
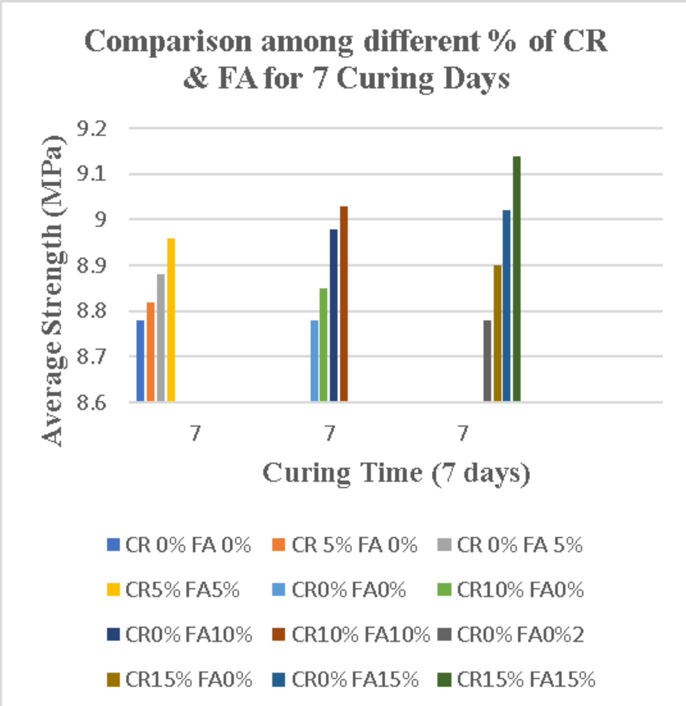


Table 14 Compressive Strength Test Results of CR & FA having different % & comparison among them for 7 curing days

Curing Time (Days)	CR %	FA %	Av. Stress (MPa)	Percentage (%)	Remarks
7	0	0	8.78	--	--
7	5	0	8.82	0.45	Increase
7	0	5	8.88	0.68	Increase
7	5	5	8.96	0.90	Increase
7	0	0	8.78	--	--
7	10	0	8.85	0.80	Increase
7	0	10	8.98	1.47	Increase
7	10	10	9.03	0.56	Increase
7	0	0	8.78	--	--
7	15	0	8.90	1.37	Increase
7	0	15	9.02	1.35	Increase
7	15	15	9.14	1.33	Increase



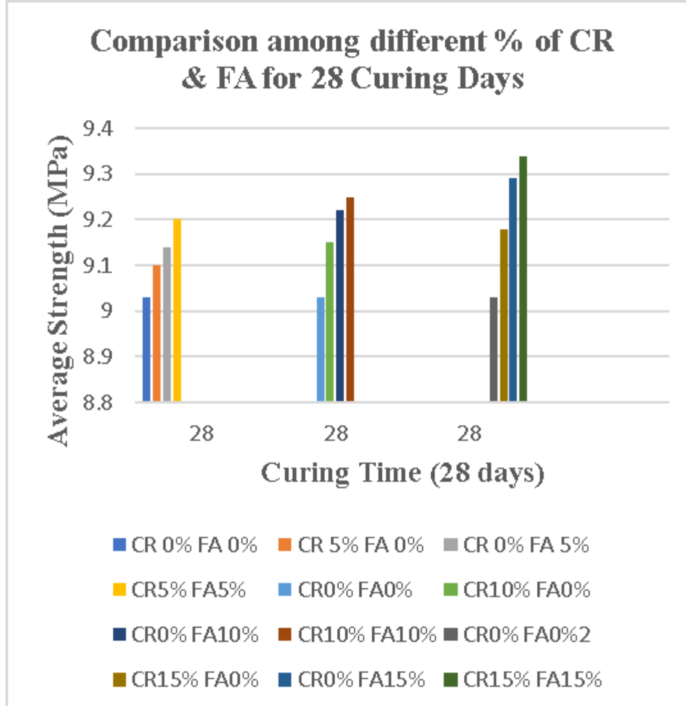


Table 15 Compressive Strength Test Results of CR & FA having different % & comparison among them for 28 curing days

Curing Time (Days)	CR %	FA %	Av. Stress (MPa)	Percentage (%)	Remarks
28	0	0	9.03	--	--
28	5	0	9.10	0.77	Increase
28	0	5	9.14	0.44	Increase
28	5	5	9.20	0.66	Increase
28	0	0	9.03	--	--
28	10	0	9.15	1.33	Increase
28	0	10	9.22	0.76	Increase
28	10	10	9.25	0.32	Increase
28	0	0	9.03	--	--
28	15	0	9.18	1.66	Increase
28	0	15	9.29	1.20	Increase
28	15	15	9.34	0.54	Increase

6 Conclusions & Recommendations

- Significant compressive strength of modified semi-rigid pavement samples achieved at 3, 7 & 28 curing days.
- Among all MSRP samples after 3 days curing at CR & FA from 5% to 15% respectively, maximum compressive strength achieved as 6.09 MPa which is 17.12% greater than normal SRP samples which is 5.20 MPa.
- Among all MSRP samples after 7 days curing at CR & FA from 5% to 15% respectively, maximum compressive strength achieved as 9.14 MPa which is 4.1% greater than normal SRP samples which is 8.78 MPa.
- Among all MSRP samples after 28 days curing at CR & FA from 5% to 15% respectively, maximum compressive strength achieved as 9.34 MPa which is 3.4% greater than normal SRP samples which is 9.03 MPa.
- Among all MSRP samples after 3,7 & 28 curing days, maximum compressive strength achieved at CR 15% & FA 15% as 9.34 MPa.
- As the percentage increase individually (CR or FA) or combination of both (CR & FA), the increment in compressive strength was shown in all samples.
- Early increment in compressive strength (3 days curing) shown more amount as compared to increment in percentage at other curing days.
- As the curing days increases, the comparison between SRP & MSRP samples shows not much greater amount in strength as compared at early stage of curing days.
- Other materials can be used instead of CR & FA in aggregate mix and cement respectively.

- Further research can be carried out by determining other mechanical properties on samples.
- Further research can be carried out by replacing the material like CR with bitumen and to find its effects on samples.
- In this study 60/70 grade of bitumen is used, which is more used in hot regions. Further research can be carried out by using different grade of bitumen.

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