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Evaluate the performance of using new materials in rigid concrete pavement

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Abstract *- Over the last years, the usage of new, environmentally friendly materials in concrete pavement is viewed and presented as a special field of researchers' study. Tire Crumb rubber (TCR) is a commodity made by re-processing (shredding) disposed of automobile tires. Shredded rubber tires have been used as a partial replacement by fine or coarse aggregates in Concrete and gained popularity. This paper presents an experimental study on the evaluation of using new materials on the rigid concrete pavement. A total of thirty-seven mix design was used to produce the mixture. Different parameters were considered during this study; the dosages of addition silica fume of the total cementitious materials weight, high Range Water Reducing Agent (HRWRA) ratio, replacement ratio of fine aggregates by rubber powder, and the ratio of (W/C). The experimental results indicated that the workability of fresh Concrete and flexural strength is remarkably enhanced by using rubber as a fine aggregate partial replacement and increasing the water-cement ratio. But replacement crumb rubber content up to 25% resulted in decreasing compressive strength up to 20%. The increasing percentage of silica fume content and HRWRA ratio increased compressive strength and flexural strength results, decreasing the rubberized Concrete's slump.*

Keywords: *Rigid Pavement, Concrete, Crumb rubber (CR), Silica fume, Super-plasticizer, Slump, Compressive strength, flexural strength.*

I. INTRODUCTION

The rigid pavement is the practical term for any road surface made of Concrete. Concrete roads are called rigid, while asphalt-covered roads are flexible. Rigid Concrete pavements are the most extensively used because of their versatile applications such as constructing airports and major highways and those in the interstate highway system. [1] One of the worldwide and critical problems is the disposal of waste materials such as tire rubber. Shredding of waste tires left behind waste products known as rubber crumb. Rubberized Concrete is a new generation of Concrete to modify Concrete's basic properties, such as workability and flexural strength. Rubberized Concrete is a full or a partial replacement of mineral aggregates with crumb rubber, resulting in a Concrete class called crumb rubber concrete (CRC) [2-11]. One of the relevant new materials is silica fume. The addition of silica fume to Concrete possesses excellent enhancement in durability, mechanical properties, modulus of elasticity, chemical, and abrasion resistance [12-13]. It is essential to pay attention that Superplasticizer (HRWRA) into the rubberized Concrete is very important to improve the Concrete's workability containing recycled rubber [14-15]. This research effort aims to evaluate the performance of using new materials in rigid concrete pavement. Numerous researches have been investigated experimentally and focused on the efficiency of using new materials in rigid concrete pavement such as fly ash, silica fume, recycled crumb rubber, and superplasticizers.

Chaitra et al. [16] studied the role of silica fume and ground granulated blast furnace slag (GGBS) on concrete strength characteristics of a high-strength test program has been accomplished. Different concrete mixtures were cast and tested with different levels of cement replacement, 40 % of GGBS with active silica fume as addition (0 %, 5 %, 10 %, 15 %, 20% and 25% by weight of cement). It was observed that 40% GGBS and 15% of Silica fume is the optimum percentage replacement of Cement in Concrete.

Umar et al. [17] presented the experimental study on concrete properties by partial replacement of Cement with 5, 10, 15%, and 20% of silica fume by weight. Concrete specimens' compressive strength is compared with concrete specimens, with no silica fume, at 7, 14, 28, and 90 day's age. A constant water-cement ratio of 0.35 is maintained, and to compensate for its workability, a superplasticizer is used. According to ASTM standards, specimens that included both 6 inches diameter cylinders and 4 inches cubes are cast and tested. Results indicated a clear improvement in the compressive strength and tensile strength properties of concrete samples by including silica fume as a partial replacement of Cement at a replacement level of 12%.

Hinislioglu and Bayrak [18] presented an attempt to optimize the early flexural strength of concrete pavement (CP) using the Taguchi Method. The experiments were designed using an orthogonal array technique in L16 array with four factors, namely, the water/cementitious and four different types of gradations with a maximum aggregate size of 32 mm, fly ash (FA) ratio from 0% to15%, and silica fume (SF) ratio from 0% to 30% by weight of Cement. Results improved that the more economical mix was obtained by using 5% FA instead of Cement.

Nochaiya et al. [19] reported the normal consistency, setting time, workability, and compressive strength results of Portland cement–fly ash–silica fume systems. The results show that water requirement for normal consistency was found to increase with increasing SF content while a decrease in initial setting time was found. Workability, measured in terms of the slump, decreased with silica fume content (compared to blends without silica fume). However, it must be noted that despite the reduction in the slump values, the workability of Portland Cement–fly ash–silica fume concrete, in most cases, remained higher than that of the Portland cement control concrete. Furthermore, the Utilization of silica fume with fly ash increased Concrete's compressive strength at early ages.

Prabhu and Subramanian [20] investigated the possibility of producing Concrete for pavement construction incorporating large volumes of industrial by-products and recycled materials. The use of industrial by-products and recycled materials in concrete pavements is continuing to see more attention. The alternative materials used as a replacement were fly ash and silica fume as a binder for cement replacement and steel slag as fine aggregate. Results revealed that increasing fly ash content enhances the workability and reduces the compressive strength and flexural strength. On the other hand, it can be noted that the addition of silica fume increases the compressive strength and flexural strength of Concrete. However, the workability of fresh Concrete was decreased.

Rana [21] presented a study on developing pavement quality concrete mixtures incorporation silica fume and nano-silica fume as partial replacement of Cement by silica fume and nano-silica fume at different w/c ratios. Results showed the maximum increase in the flexural strength and compressive strength by 5% silica fume and 2% nano-silica fume at w/c of 0.4.

Kumar [22] studied the effect of pozzolanic material (Metakaolin and Silica fume) on the compressive and Flexural strength in cement concrete. Metakaolin and silica fume are used as cement replacement materials at 5%, 10%, and 15% by mass, keeping the water-cement ratio as 0.42. Results indicated that the replacement of Silica Fume increases the Flexural Strength at all ages of curing. However, the optimal dose is 10% up to 1.5% higher than plain Concrete.

Han et al. [23] investigated an experimental and numerical analysis studying material properties and damaged plasticity models of Concrete with four different rubber contents. Four different rubber contents of 0%, 5%, 10% and 15% and four stud dimensions are considered. The results revealed that the single stud's ultimate strength in crumb rubber concrete with 5%, 10%, and 15% rubber contents has decreased by 1.36%, 3.07%, and 6.62%, respectively, ordinary Concrete.

II. EXPERIMENTAL PROGRAM

A. Material properties

Materials used in the specimens' construction were: national Ordinary Portland Cement (OPC), silica fume, siliceous sand, crushed gravel, superplasticizer, recycled crumb rubber, and tap drinking water.

- ***Cement***

Portland cement is the foremost among the construction materials, which acts as a binder that holds fine and micro-fine particles. In the simple form, Concrete is a mixture of paste and aggregates. The paste consists of Portland cement and water and coats the surface of fine and coarse aggregates. Its versatility, and adaptability, as evidenced by the many types of construction in which it is used and minimum maintenance required during its service life. Table 1 shows the chemical properties of the Used Cement.

- **Aggregates**

All aggregates used in this research were available locally. To avoid the aggregates' fine materials, all aggregates were washed before casting for about 48 hours and left to dry. Table 2 shows the particle size distribution for used aggregates. The properties of the aggregates were as follows:

- ***Coarse Aggregate***

The coarse aggregate used was local crushed gravel from natural resources obtained from El-wadi El-assuitey, Assuit. The surface texture is relatively rough.

- ***Fine Aggregate***

This investigation's fine aggregate was natural siliceous sand with grain size ranging from 0.15 to 0.5 mm.

- ***Additives:***
- ***Silica Fume:***

Silica fume was used to add to the Cement with a dosage from 5% up to 25% of the cement content, as shown in Figure 1. The used silica fume is commercially available through Metallurgical and construction chemical company. The chemical composition is shown in Table 1, as obtained from the manufacturer datasheet.

Figure 1 Silica fume

Table 1 Chemical properties of the used Cement and silica fume

Chemical Properties	Cement	Silica Fume
SiO_2	21.0 %	97%
Al_2O_3	5.3 %	0.2%
Fe_2O_3	3.51 %	0.5%
CaO	63.29 %	0.2%
MgO	1.02 %	0.5%
SO3	2.12 %	0.16%
Na2o	0.4 %	0.21%
K2o	0.12%	0.5%
CI	0.01%	< 0.01%
C_3A	8.11%	0.5%
PH	--------	6%
Loss ignition	2.56%	--------
H_2o		0.50%

- ***Recycled crumb rubber***

The concrete materials were blended with the recycled rubber (0.85-3.5) mm replacement of fine aggregate by volume with (0, 5, 10, 15, 20, and 25) % to achieve the desired properties. Rubber was produced from the Sama United Recycling factory in Ismailia, as shown in Figure 2. Its properties are presented in Table2.

Figure 2 Recycled Crumb Rubber

Table 2 Sieve analysis of aggregate types

Sieve size (mm)	Passing (%)		
	Coarse aggregate	**Fine aggregate**	**Rubber**
50	100	100	100
37.5	100	100	100
20	100	100	100
14	100	100	100
10	80.66	100	100
5	13.17	98.8	100
2.36	------	95.25	98.32
1.18	------	88.7	73.95
0.6	------	72.89	70.15
0.3	------	23.11	70.15
0.15	------	3.12	70.15

- ***Chemical Admixture:***

To achieve the product concrete, commercially available HRWRA (Sika 2004 R) was used. The admixture meets the requirements for superplasticizers, according to EN 934-2. In this research, the dose of the superplasticizer was selected based on the workability of the mix.

- ***Mixing Water:***

Clean drinking fresh water free from impurities was used for mixing.

B. Mix design

Various trials were conducted to get the optimum design mix. The standard mix design is used for all the experiments. One mix was used to cast the specimens, and it was designed to target 28 days compressive strength of 40-50 MPa. Many mixes were developed through trial batching in the Material Testing Laboratory Faculty of Engineering, South Valley University. After the selection of needed constituent materials, all materials were appropriately weighed. Mixing was done using a rotary electric concrete mixer (Lino Sella) of 0.1 m3 capacity to mix the concrete ingredients. The water-reducing admixture was added to the mixing water before mixing. A special way of mixing was used to ensure the mix's homogeneity: Firstly, course and intermediate aggregates are placed in a drum with approximately a quarter of the mixing water, and the mixer ran for 1 min. Secondly, sand and crumb rubber was then added and mixed for 2 minutes, and finally, Cement and the remaining mixing water were added and mixed for 3 min, rested for 3 min, and mixed for 2 min as a final stage. Concrete constituents were batched (added) separately by weight using a digital balance of 0.1 kg sensitivity. Mixed Concrete was placed in the molds and compacted mechanically by internal electrical vibrator and hand taping and rodding to ensure full compaction of the Concrete inside the molds. To evaluate the workability of the fresh Concrete, a slump flow test was carried out according to ECP203 as viewed in **Figure 3.a**. Cubes (15x15x15) cm and prisms (10x10x50) cm were prepared and cast for compressive and flexure strength test according to ECP203, are shown in **Figure 3.b**, and **Figure 3.c**. The molds were removed after 24 hours from casting, and the cubes were cured in a water tank with an average temperature of 25^o C until testing at 7 and 28 days, respectively, as shown in **Figure 3.d**.

C. Description of the test specimens

Table 3 summarizes the overall description of tested mixes of the used Concrete. A total of 25 mixes were designed and cast to produce the mixture, a reference (control mix), and devoted to studying plain Concrete's behavior without any additional new materials, representing mix (Mo). The super-plasticizers HRWRA Sika 2004 were added with a dosage ranging from 0%, 2%, and 3%. At the same time, to study the effect of addition silica fume from 0 up to 20%, with 2% HRWRA Sika 2004 R, to study the effect of fine aggregate replacement by rubber powder from (0%-25%) with 2% HRWRA Sika 2004 R.

Figure3.a Slump test preparation

Figure3.b Concrete cube for each mix.

Figure 3.c Beams for flexure test

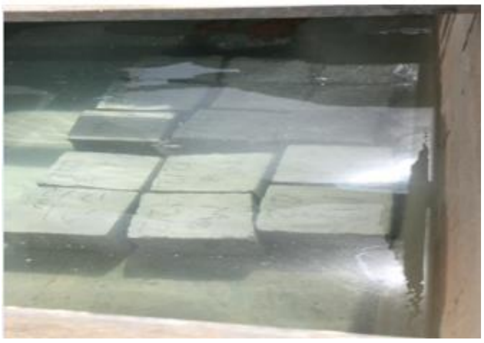

Figure3.d Concrete cubes are curing.

Figure 3 Preparation for experimental test

Table 3 Properties of tested mixes

Mix	Group	Cement (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	Water (kg/m^3)	HRWRA%	Silica fume(kg/m^3)	Rubber powder(kg/m^3)
Mo	Go	400	660	1210	180	0%	0	0
M1	G1	450	660	1210	180	3%	0	0
M2	G2	450	660	1210	180	2%	22.5	0
M3			627					33
M4			594					66
M5			561					99
M6			528					132
M7			495					165
M8	G3	450	660	1210	180	2%	45	0
M9			627					33
M10			594					66
M11			561					99
M12			528					132
M13			495					165
M14	G4	450	660	1210	180	2%	67.5	0
M15			627					33
M16			594					66
M17			561					99
M18			525					132
M19			495					165
M20	G4	450	660	1210	180	2%	90	0
M21			627					33
M22			594					66

M23			561					99
M24			528					132
M25			495					165

III. TEST RESULTS

A. Slump Results

Twelve selected mixes were prepared and tested to obtain the effect of various factors on fresh Concrete's workability. The slump results were summarized in **Table 4** and displayed using a bar chart in **Figure 4**. The fresh Concrete's workability is remarkably enhanced by increasing superplasticizer (high range water reducing agent) content at a concrete mix. Results indicated increasing **the** HRWRA ratio from 2 to 3% for mixes M8 and M1 resulted in an increasing slump from 40 to 80 mm. HRWRA produced the same electrostatic charges on the cement particle's surface. This, due to the repulsion among the cement particles, prevented the coagulation and minimized the air-entrained. Consequently, the fluidity of the Concrete increased. Therefore, the particles have greater mobility, and water freed from the flocculated system's restraining influence becomes available to lubricate the mix, resulting in increasing workability. Experimental results indicated that increasing silica fume content to the concrete mix by 5, 10, 15, and 20% at the same amount of superplasticizer resulted in a significant decrease in the concrete slump. They were using rubber as an acceptable aggregate partial replacement induced, increasing the workability of fresh-state Concrete. Results revealed that using crumb rubber with ratios 0, 5, 10, 15, 20, and 25% resulted in a remarkable increase in fresh Concrete's workability, and thus slump was increased.

Table 4 Slump Results

Mix	Slump
M1	80
M2	55
M3	59
M4	63
M5	66
M6	71
M7	76
M8	40
M14	30
M20	20

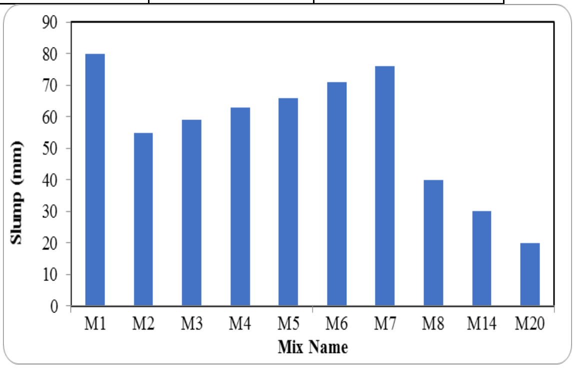

Figure 4 The slump results

B. Concrete Compressive Strength Results

Three test cubes were made for each mix at age (7 and 28 days) to investigate the studied parameters' effect on the compressive strength. Table 4.2 shows the compressive strength for each mix. Figure 5.a reported that increasing HRWRA content to 3% resulted in increasing compressive strength to 3.5% compared with mixed M8 with HRWRA 2%. The incorporation of silica fume is essential to achieve high mechanical properties. Figure 5.b showed that as the silica fume content increased, the compressive strength increased. The enhancement of compressive strength can be attributed to the micro filler effect and excellent pozzolanic properties of silica fume. The use of silica fume in Concrete improves the calcium silicate hydrate (C-S-H) gel formation resulting in high strength, high durability of concrete structures, and reduction of voids in the concrete mix. Figure 5.c revealed that replacement crumb rubber content up to 25% for mixed M8 decreased compressive strength up to 20% than mixed M2 without rubber replacement. Figure 4.d showed decreasing compressive
strength up to 17.44% for mix M13 with 25% rubber content than control mix M8 with 0% rubber content. Figure 5.e revealed that silica fume's addition with 15% and 25% rubber replacement ratio decreased compressive strength up to 14.44% in mixed M19 than control mix M14 (without rubber replacement). A decrease was observed in the rubberized Concrete's compressive strength up to 13.18% than the control mix without rubber replacement when the rubber replacement ratio was 25 %, as shown in Figure 5.f. In general, it is noted that concrete mixes that contained a high rubber replacement ratio caused a sharp decrease in compressive strength, the poor chemical interaction between the concrete mix and rubber, causing little or no adhesion at the interface of the concrete/rubber is considered to be the main
purpose of the decrease in the compressive strength of Concrete.

Table 4.2 The compressive strength results

Mix	Group	Compressive strength (MP		Reduction%	
		7 Days	28 Days	7 Days	28 Days
M1	G1	330	445	-----	-----
M2	G2	317	400	-----	-----
M3		290	384	-8.5	-4
M4		275	356	-13.25	-11
M5		267	344	-15.77	-14
M6		262	328	-17.35	-18
M7		241	320	-24	-20
M8	G3	320	430	-----	-----
M9		315	418	-1.56	-2.80
M10		289	385	-9.7	-10.46
M11		278	372	-13.12	-13.49
M12		270	360	-15.62	-16.28
M13		267	355	-16.56	-17.45
M14		330	450	-----	-----
M15		325	440	-1.5	-2.22
M16		315	425	-4.55	-5.56
M17		307	411	-7	-8.67
M18		302	400	-8.50	-11.12
M19		230	385	-30.30	-14.44
M20		307	478	-----	-----
M21		302	460	-1.63	-3.76
M22		297	457	-3.26	-4.40
M23		288	440	-6.20	-7.95
M24		327	282	-8.15	-9
M25		273	415	-11	-13.18

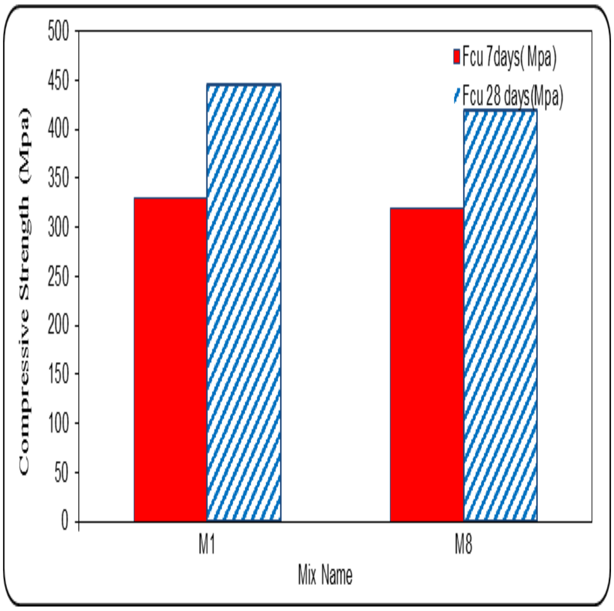

Figure 5.a Effect of High Range Water Reducing Agent Ratio on Compressive Strength

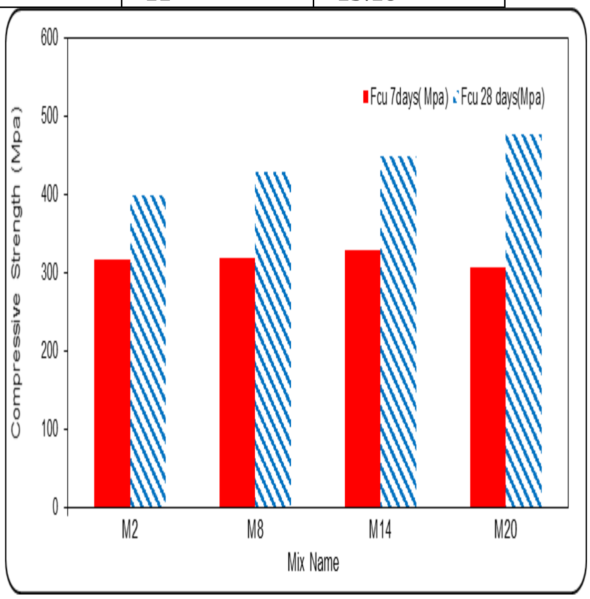

Figure 5.b Effect of addition Silica Fume on Compressive Strength

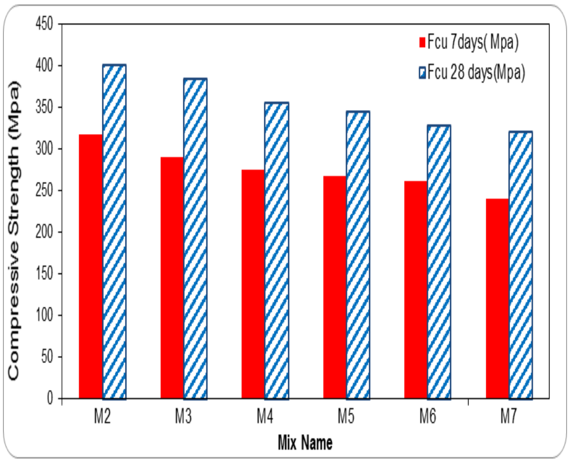

Figure 5.c Effect of addition Crumb Rubber on Compressive Strength (G2)

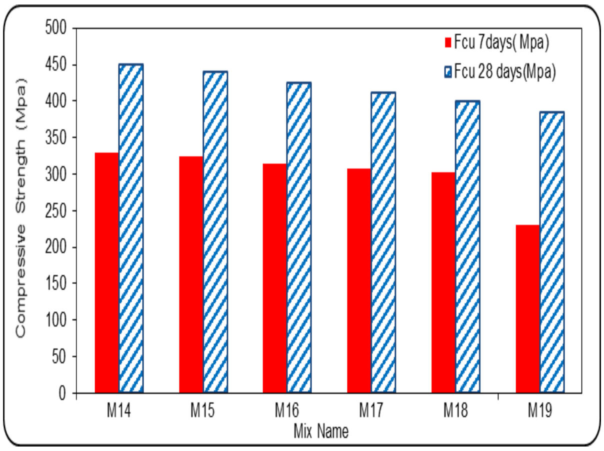

Figure 5.e Effect of addition Crumb Rubber on Compressive Strength (G4)

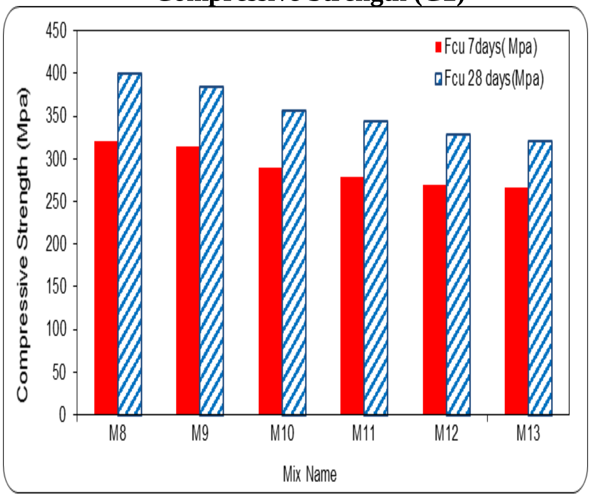

Figure 5.d Effect of addition Crumb Rubber on Compressive Strength (G3)

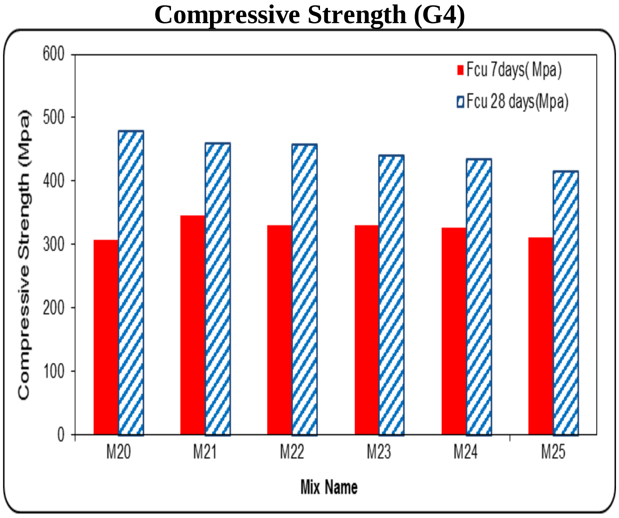

Figure 5.f Effect of addition Crumb Rubber on Compressive Strength (G5)

Figure 5 Compressive Strength Results

C. Flexural Strength Results

Ten tested specimens for selected mixes were prepared and tested at 28 days to study these concrete mixes' flexural behavior. **Table 6** and **Figure 6** shows the flexure strength test results for all specimens. Results illustrated that increasing the HRWRA ratio at the same silica fume content resulted in a significant increase in flexure strength. Flexure strength in mix M1 increased by 19.40% than M8. It can be concluded that increasing the percentage of silica fume content to 10% in specimen S8 resulted in increasing flexure strength by 9.55% than S2 with 5% silica fume content. The experimental observations reported that when silica fume is incorporated, the cement hydration rate increases at the early hours due to the release of OH ions and alkalis into the pore fluid. So the C±S±H gel is the main purpose of enhancing the flexure strength characteristics of Concrete. The replacement of fine aggregate by rubber from 5, 10, 15, 20, and 25% in specimens S3, S4, S5, S6, and S7 slightly increased the Concrete's flexural strength by percentages of 1.5, 3.2, 4.55, 7, and 8.25%, respectively above control specimen S2 without rubber replacement .

Table 6 Flexural Strength Results

Specimen	Mix	exure Strength28 day (Mpa)	Increasing %
S1	M1	4.23	------
S2	M2	4.61	------
S3	M3	4.68	1.5
S4	M4	4.76	3.2
S5	M5	4.82	4.55
S6	M6	4.93	7
S7	M7	4.99	8.25
S8	M8	5.05	9.55

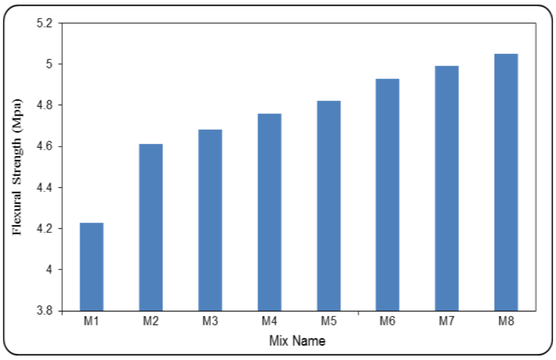

Figure 6 Flexural Strength Results

IV. CONCLUSIONS

Based on the results and observations of the experimental investigations presented in this research regarding the effectiveness of silica fume on the properties of cement concrete for rigid pavement, the following conclusions can be drawn:-

1. The workability of fresh Concrete is remarkably enhanced by using rubber as a fine aggregate partial replacement and increasing the water-cement ratio. But, increasing silica fume dosage decreases the rubberized Concrete's slump.
2. Good compressive strength results were recorded when crumb rubber contents lower than 25% in replacement of crushed sand, which has a positive outlook, especially for surface pavement applications.
3. Results indicated that increasing high-range water reduction agent content resulted in a significant increase in workability, compressive strength, and flexural strength.
4. The increasing percentage of silica fume content resulted in increasing compressive strength and flexural strength results.
5. Increasing the HRWRA ratio at the same silica fume content resulted in an influence on compressive strength and flexure strength.
6. Experimental investigations revealed that replacement crumb rubber content up to 25% resulted in decreasing compressive strength up to 20%
7. The addition of crumb rubber up to 25% as a fine aggregate replacement improved the Concrete's flexural strength.

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