



Experimental Study on Standard and High-Strength Concrete Incorporating Waste Tyre Rubber and Silica Fume

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Abstract. This study investigates M40 standard-grade and M70 high-strength concrete incorporating waste tyre rubber as partial replacement of natural fine and coarse aggregates together with silica fume. The experimental programme evaluates workability, compressive strength, split tensile strength, flexural strength, stress-strain behaviour, Young's modulus, rebound number, ultrasonic pulse velocity, sorptivity and resistance to 5% MgSO₄, HCl and H₂SO₄ solutions. The mixes include control concrete, concrete with 4% silica fume, concrete with 4% coarse waste tyre rubber and silica fume, and concrete containing both fine and coarse waste tyre rubber. The study reports 264 specimens, with 132 specimens for each concrete grade. Results show that increasing tyre-rubber content reduces workability and mechanical strength because of weak bonding between rubber particles and cement paste. The target mean strength was obtained for rubberized concrete containing 4% coarse rubber and 4% silica fume, while the required target mean strength was not achieved for M70 rubberized concrete. Non-destructive, sorptivity and chemical-exposure results provide additional assessment of quality and durability.

Keywords: Waste tyre rubber; Rubberized concrete; Silica fume; M40 concrete; M70 concrete; Mechanical properties; Sorptivity; UPV; Durability.

I. Introduction

Concrete production requires large quantities of cement and natural aggregates. The source study identifies increasing scarcity and cost of conventional aggregates together with the environmental problem created by discarded waste tyres. Waste tyre rubber is durable and non-biodegradable, and its use as a partial aggregate replacement offers a possible route for reducing tyre disposal and natural aggregate consumption.

Rubberized concrete can exhibit improved energy absorption, ductility and resistance to cracking, but the incorporation of rubber generally reduces compressive strength and modulus of elasticity. The study therefore combines waste tyre rubber with silica fume, which is used as a highly reactive pozzolanic material to improve strength and reduce permeability.

Objectives and scope

- To study the fresh and hardened properties, including slump, compressive strength, flexural strength, split tensile strength and stress-strain behaviour of M40 and M70 concrete.



- To study durability through acid attack, sulphate attack and sorptivity tests.
- To evaluate concrete quality using rebound hammer and ultrasonic pulse velocity tests.
- To investigate M40 and M70 concrete in which fine and coarse aggregates are partially replaced with waste tyre rubber.

II. Literature Review

Observed the extensive microcracking in the tire rubber particle vicinity, which weakens the bond between tire rubber particles and the cement paste matrix. This confirms the fact that the soft behavior of the tire particles produces tensile strains at the tire rubber particle surface, which causes microcracking in the cement paste vicinity. The results of surface contact angle for rubber particles treated with analytically pure anhydrous ethanol (AE) solvent, acrylic acid (ACA) and polyethylene glycol (PEG) indicates that the unmodified rubber surface is hydrophobic with a surface contact angle of 105.13° . However, the modified rubber surface was developed into the hydrophilic one with a contact angle of 68.00° .

Sara(2010), investigated the use of rubber particles from recycled tires as concrete aggregate to improve mechanical properties and workability, and air entrapment through the use of three types of scraps such as ash rubber, crumb rubber and tire chips.

Ling et al.(2012) reported a reduction in the compressive strength of concrete blocks at ages of 7 and 28 days by replacing natural sand (size 4 mm) with rubber (size 5–1 mm) at levels ranging from 5% to 50%, by volume. Different w/b ratios of 0.45, 0.5 and 0.55 were used. This reduction increased with increasing rubber sand content. The reduction in the 28 days compressive strength at w/c ratio of 0.45 was 2.27%, 18.83%, 24.35%, 33.77%, 35.39%, 48.7%, 65.91% and 69.165% with the inclusion of 5%, 10%, 15%, 20%, 25%, 30%, 40% and 50% rubber sand, respectively.

Abas et al. (2015), Studied the fresh and hardened state properties such as Slump, wet density, compressive strength, flexural strength and toughness indices. It was reported that the compressive strength values of all waste tire rubber concrete mixtures decreased with the increasing waste tire rubber ratio at all curing ages. Flexural strength also decreased with increase in the rubber content, and also had less flexural strength at 56 days when it was replaced by 20% of the crumb rubber. It was found that dry density and slump values also decrease with increase in the rubber content. Load deflection curves of the concrete mixtures that contain waste tyre rubber showed arrest of propagation of micro cracks.

Nithiya et al.(2017), made M20 grade concrete mixes by replacing fine aggregate with 5%, 10%, 15% and 20% with crumb rubber. It was concluded that compressive strength decreases with increasing fine aggregate with the replacement of crumb rubber and showed that 5% replacement is exceptionally well in compressive strength and



tensile strength giving more 28- day compressive strength and reduced split tensile strength upto 25% when crumb rubber is replaced to 10% of fine aggregate.

III. Materials and Methods

The materials used were 53-grade Ordinary Portland Cement, natural fine aggregate, crushed granite coarse aggregate, potable water, FOSROC SP-430 superplasticizer, silica fume, crumb rubber powder and coarse waste tyre rubber aggregate. The waste tyre rubber was obtained from recycled tyres and was used as partial replacement of conventional aggregate.

The control mix proportions by weight were 1:1.4:1.77:0.38 for M40 concrete and 1:0.77:1.5:0.26 for M70 concrete. Concrete was mixed in a 50-L pan mixer. Dry materials were mixed first, followed by water and superplasticizer. Specimens included cubes, cylinders and prisms and were water-cured for 7 and 28 days.

The test programme consisted of 48 standard cubes, 48 cylinders, 24 prisms and 144 small cubes. A total of 264 specimens were reported, comprising 132 specimens for M40 and 132 for M70. Tests included compressive strength, split tensile strength, flexural strength, modulus of elasticity, rebound hammer, UPV, sorptivity and chemical resistance.

Mix proportions and specimen programme

Table 1. Ingredient content of concrete mixes (kg/m³) - M40 grade concrete.

Descrip- tion	Cement	Silica fume	Fine ag- gregate	Fine waste tyre rub- ber	Coarse aggre- gate	Coarse waste tyre rub- ber	Water
A-0	526.32	0	739.53	0	930.56	0	200
A0-4	505.27	21.05	739.53	0	930.56	0	200
A4-4	505.27	21.05	739.53	0	893.33	37.22	200
A4-4-4	505.27	21.05	709.95	29.58	893.33	37.22	200

Table 2. Ingredient content of concrete mixes (kg/m³) - M70 grade concrete.

De- scrip- tion	Ce- ment	Silica fume	Fine aggre- gate	Fine waste tyre rubber	Coarse aggre- gate	Coarse waste tyre rubber	Super plasti- cizer (ml)	Water
B-0	695.96	0	532.77	0	1046.88	0	7655.56	180.95
B0-4	668.12	27.84	532.77	0	1046.88	0	7655.56	180.95
B4-4	668.12	27.84	532.77	0	1005.00	41.88	7655.56	180.95
B4-4- 4	668.12	27.84	511.46	21.31	1005.00	41.88	7655.56	180.95



Table 3. Details of specimens cast - M70 grade concrete.

Mix Designation	No. of Cubes (150x150)	No. of Cubes (100 x 100)	No. of Cylinders	No. of Prisms	Total
B0 (Nominal Mix)	6	0	6	3	15
B0-4 (4% SF)	6	0	6	3	15
B4-4 (4% waste tyre rubber waste+ 96% CA + 4 % SF + 1.3% SP)	6	36	6	3	51
B4-4-4 (4% waste Tyre rubber waste + 96% CA + 96% FA + 4% SF + 1.3% SP)	6	36	6	3	51
Total Number of specimens	24	72	24	12	132

Table 4. Details of specimens cast - M40 grade concrete.

Mix Designation	No. of Cubes (150 x 150)	No. of Cubes (100 x 100)	No. of Cylinders	No. of Prisms	Total
A0 (Nominal Mix)	6	0	6	3	15
A0-4 (4% SF)	6	0	6	3	15
A4-4 (4% waste tyre rubber waste+ 96% CA + 4 % SF)	6	36	6	3	51
A4-4-4 (4% waste Tyre rubber waste + 96% CA + 96% FA + 4% SF)	6	36	6	3	51
Total Number of specimens	24	66	24	12	132

Table 5. Slump values of fresh concrete with various ratios of tyre rubber waste - M40 grade concrete.

S.No	Mix Designation	Slump
1	A0	65
2	A0-4	55
3	A4-4	14
4	A4-4-4	12

Table 6. Slump values of fresh concrete with various ratios of tyre rubber waste - M70 grade concrete.

S.NO	Mix Designation	Slump
1	B0	80
2	B0-4	0
3	B4-4	0
4	B4-4-4	0



Experimental Materials and Test Setup



Fig. 1 Crumb rubber [fine and coarse aggregate rubbers]



Plate 2: casting of specimens



Plate 5: split tensile strength on cylinder



IV. Results and Discussion

The experimental results include compressive strength, split tensile strength, flexural strength, stress-strain behaviour, Young's modulus, ultrasonic pulse velocity, rebound number, sorptivity and resistance to acid and sulphate attack for M40 and M70 concrete.

Table 7. Physical Properties of Ordinary Portland Cement (OPC-53).

Sl.no.	Property	Test Method	Test Result
1	Normal consistency	Vicat apparatus (IS 4031-Part IV)	34%
2	Specific gravity	Specific gravity bottle (IS 4031-Part II)	3.15
3	Initial setting time	Vicat apparatus (IS 4031-Part V)	45 min
4	Final setting time	Vicat apparatus (IS 4031-Part V)	175min
5	Fineness	Sieve test on sieve no.9 (IS 4031-Part IV)	6%

Table 8. Physical Properties of CA, FA & Waste Tyre Rubber.

S.No	Property	Conventional Coarse aggregate	Fine aggregate	Waste Tyre rubber(F)	Waste Tyre rubber(C)
1	Specific Gravity	2.77	2.67	1.78	1.13
2	Bulk Density	1.454g/cc	1.292g/cc	0.4g/cc	0.47g/cc
3	Fineness Modulus	7.18	2.63	4.2	7.63
4	Water Absorption	0.46%	1%	2%	0.99%

Table 9. Compressive Strength of Waste Tyre Rubber Concrete - M40 Grade.

S.No	Mix	Silica fume Content (%)	Compressive Strength(N/mm ²) 7days	Compressive Strength(N/mm ²)28days
1	A0	0	30.21	51.09
2	A0-4	4	34.56	56.80
3	A4-4	4	32.89	48.10
4	A4-4-4	4	27.9	41.10

Table 10. Compressive Strength of Waste Tyre Rubber Concrete - M70 Grade.

S.No	Mix	Silica fume Content(%)	Compressive Strength(N/mm ²) 7days	Compressive Strength(N/mm ²)28days
1	B0	0	48.09	60.3
2	B0-4	4	51.27	64.60
3	B4-4	4	31.95	48.06
4	B4-4-4	4	27.30	43.62



Table 11. Split Tensile Strength of Waste Tyre Rubber Concrete - M40 Grade.

28 days Split Tensile Strength-M40 Grade Concrete	28 days Split Tensile Strength-M40 Grade Concrete	28 days Split Tensile Strength-M40 Grade Concrete	28 days Split Tensile Strength-M40 Grade Concrete
S.No	Mix	Silica fume Content (%)	Split tensile Strength(N/mm ²)
1	A0	0	3.10
2	A0-4	4	2.9
3	A4-4	4	2.786
4	A4-4-4	4	2.359

Table 12. Split Tensile Strength of Waste Tyre Rubber Concrete - M70 Grade.

28 days Split Tensile Strength-M70 Grade Concrete	28 days Split Tensile Strength-M70 Grade Concrete	28 days Split Tensile Strength-M70 Grade Concrete	28 days Split Tensile Strength-M70 Grade Concrete
Sl.No	Mix	Silica fume Content (%)	Split tensile Strength(N/mm ²)
1	B0	0	2.39
2	B0-4	4	2.46
3	B4-4	4	2.34
4	B4-4-4	4	2.22

Table 13. Flexural Strength of Waste Tyre Rubber Concrete - M40 Grade.

S.No	Mix	Silica fume Content (%)	Flexural strength 28 days (N/mm ²)
1	A0	0	1.72
2	A0-4	4	2.03
3	A4-4	4	1.551
4	A4-4-4	4	1.418

Table 14. Flexural Strength of Waste Tyre Rubber Concrete - M70 Grade.

Sl.No	Mix	Silica fume Content (%)	Flexural strength 28 days (N/mm ²)
1	B0	0	1.56
2	B0-4	4	1.87
3	B4-4	4	1.39
4	B4-4-4	4	1.32

Table 15. Weight loss and strength loss of M40 grade waste tyre rubber concrete with CA replacement under 5% MgSO₄, HCl and H₂SO₄ exposure.

Type and percentage of solution	Weight and comp. strength of cube	15 days	30 days	45 days	60 days	90 days
5% MgSO ₄	Wt. before	2.48	2.49	2.49	2.48	2.51



5% MgSO ₄	Wt. after	2.49	2.503	2.509	2.49	2.53
5% MgSO ₄	% wt loss	- 0.40	- 0.52	- 0.76	- 0.40	- 0.79
5% MgSO ₄	C.S before	44.93	44.93	44.93	44.93	44.93
5% MgSO ₄	C.S after	44.32	44.24	43.71	43.9	42.4
5% MgSO ₄	% C.S loss	1.35	1.53	2.71	2.29	5.63
5% HCl	Wt. before	2.485	2.486	2.48	2.482	2.47
5% HCl	Wt. after	2.469	2.445	2.42	2.43	2.327
5% HCl	% wt loss	0.64	1.64	2.41	2.095	5.789
5% HCl	C.S before	44.93	44.93	44.93	44.93	44.93
5% HCl	C.S after	42.26	40.75	38.79	37.86	33.2
5% HCl	% C.S loss	5.94	9.30	13.66	15.73	26.10
5% H ₂ SO ₄	Wt. before	2.492	2.483	2.486	2.497	2.481
5% H ₂ SO ₄	Wt. after	2.355	2.277	2.261	1.988	1.836
5% H ₂ SO ₄	% wt loss	5.49	8.29	9.05	20.38	25.9
5% H ₂ SO ₄	C.S before	44.93	44.93	44.93	44.93	44.93
5% H ₂ SO ₄	C.S after	33.8	26.5	25.3	24.0	19.9
5% H ₂ SO ₄	% C.S loss	24.77	41.01	43.69	46.58	55.70

Table 16. Weight loss and strength loss of M40 grade waste tyre rubber concrete with FA and CA replacement under 5% MgSO₄, HCl and H₂SO₄ exposure.

Type and percentage of solution	Weight and comp. strength of cube	15 days	30 days	45 days	60 days	90 days
5% MgSO ₄	Wt. before	2.37	2.36	2.38	2.37	2.37
5% MgSO ₄	Wt. after	2.39	2.38	2.39	2.387	2.384
5% MgSO ₄	% wt loss	- 0.843	- 0.847	- 0.420	- 0.717	- 0.590
5% MgSO ₄	C.S before	41.47	41.47	41.47	41.47	41.47
5% MgSO ₄	C.S after	39.12	37.55	38.37	37.4	36.75
5% MgSO ₄	% C.S loss	5.66	9.45	7.47	9.81	11.38
5% HCl	Wt. before	2.51	2.55	2.47	2.46	2.43
5% HCl	Wt. after	2.390	2.475	2.313	2.32	2.337
5% HCl	% wt loss	4.78	2.94	6.35	5.69	3.82
5% HCl	C.S before	41.47	41.47	41.47	41.47	41.47



5% HCl	C.S after	40.2	39.4	39.5	38.7	38.9
5% HCl	% C.S loss	3.06	4.99	4.75	6.67	6.19
5% H ₂ SO ₄	Wt. before	2.44	2.41	2.43	2.39	2.38
5% H ₂ SO ₄	Wt. after	2.272	2.17	2.128	2.083	1.905
5% H ₂ SO ₄	% wt loss	6.88	9.95	12.42	12.84	19.95
5% H ₂ SO ₄	C.S before	41.47	41.47	41.47	41.47	41.47
5% H ₂ SO ₄	C.S after	34.2	28.0	22.7	18.85	16.1
5% H ₂ SO ₄	% C.S loss	17.53	32.48	45.26	54.54	61.17

Table 17. Weight loss and strength loss of M70 grade waste tyre rubber concrete with CA replacement under 5% MgSO₄, HCl and H₂SO₄ exposure.

Type and percent- age of so- lution	Weight and comp. strength of cube	15 days	30 days	45 days	60 days	90 days
5% MgSO ₄	Wt. before	2.395	2.39	2.41	2.38	2.389
5% MgSO ₄	Wt. after	2.410	2.405	2.5	2.45	2.455
5% MgSO ₄	% wt loss	- 0.62	- 0.62	- 3.7	- 2.9	- 2.7
5% MgSO ₄	C.S before	47.45	47.45	47.45	47.45	47.45
5% MgSO ₄	C.S after	45.32	44.68	45.57	44.12	43.76
5% MgSO ₄	% C.S loss	4.48	5.83	3.96	7.01	7.77
5% HCl	Wt. before	2.387	2.395	2.42	2.415	2.399
5% HCl	Wt. after	2.31	2.285	2.337	2.329	2.283
5% HCl	% wt loss	3.23	4.59	3.42	3.56	4.85
5% HCl	C.S before	47.45	47.45	47.45	47.45	47.45
5% HCl	C.S after	36.54	39.76	37.54	32.22	31.89
5% HCl	% C.S loss	22.99	16.20	20.88	32.09	32.79
5% H ₂ SO ₄	Wt. before	2.380	2.389	2.40	2.391	2.344
5% H ₂ SO ₄	Wt. after	2.27	2.265	2.255	2.272	2.193
5% H ₂ SO ₄	% wt loss	4.62	5.19	6.04	4.97	6.44
5% H ₂ SO ₄	C.S before	47.45	47.45	47.45	47.45	47.45
5% H ₂ SO ₄	C.S after	35.45	32.54	26.83	27.59	25.12
5% H ₂ SO ₄	% C.S loss	25.28	31.42	43.45	41.85	47.06



Table 18. Weight loss and strength loss of M70 grade waste tyre rubber concrete with FA and CA replacement under 5% MgSO₄, HCl and H₂SO₄ exposure.

Type and percentage of solution	Weight and comp. strength of cube	15 days	30 days	45 days	60 days	90 days
5% MgSO ₄	Wt. before	2.352	2.402	2.33	2.35	2.252
5% MgSO ₄	Wt. after	2.375	2.41	2.452	2.42	2.32
5% MgSO ₄	% wt loss	-0.97	-0.33	- 5.23	- 2.9	- 3.01
5% MgSO ₄	C.S before	43.85	43.85	43.85	43.85	43.85
5% MgSO ₄	C.S after	42.4	42.8	41.7	41.4	40.89
5% MgSO ₄	% C.S loss	3.30	2.39	4.90	5.58	6.75
5% HCl	Wt. before	2.49	2.46	2.38	2.44	2.33
5% HCl	Wt. after	2.402	2.452	2.352	2.252	2.25
5% HCl	% wt loss	3.53	0.32	1.17	7.70	3.43
5% HCl	C.S before	43.85	43.85	43.85	43.85	43.85
5% HCl	C.S after	43.12	42.62	42.33	41.89	41.55
5% HCl	% C.S loss	1.66	2.80	3.46	4.46	5.24
5% H ₂ SO ₄	Wt. before	2.452	2.402	2.44	2.34	2.24
5% H ₂ SO ₄	Wt. after	2.322	2.22	2.078	2.033	1.955
5% H ₂ SO ₄	% wt loss	4.89	7.57	14.83	13.11	12.72
5% H ₂ SO ₄	C.S before	43.85	43.85	43.85	43.85	43.85
5% H ₂ SO ₄	C.S after	32.89	27.43	25.64	21.22	16.64
5% H ₂ SO ₄	% C.S loss	24.99	37.44	41.52	51.60	62.05

Table 19. Rebound number and UPV - M40 grade concrete.

S.No	Mix	Silica fume Content (%)	Rebound Number	UPV(km/s)
1	A0	0	45	4.126
2	A0-4	4	45	4.186
3	A4-4	4	37	4.476
4	A4-4-4	4	34	4.433

Table 20. Rebound number and UPV - M70 grade concrete.

S.No	Mix	Silica fume Content (%)	Rebound Number	UPV(km/s)
1	B0	0	49	3.411
2	B0-4	4	42	3.204
3	B4-4	4	36	4.405
4	B4-4-4	4	28	4.285

Table 21. Sorptivity of waste tyre rubber concrete - M40 grade.

S.No	Mix	Silica fume content	30min	60min	90min	120min	150min	180min	210min
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1	A4-4	4	0.335	0.281	0.262	0.215	0.187	0.164	0.153
2	A4-4-4	4	0.325	0.277	0.248	0.203	0.181	0.165	0.154

Table 22. Sorptivity of waste tyre rubber concrete - M70 grade.

S.No	Mix	Silica fume content	30min	60min	90min	120min	150min	180min	210min
1	B4-4	4	0.346	0.295	0.262	0.233	0.208	0.177	0.156
2	B4-4-4	4	0.334	0.287	0.259	0.225	0.193	0.176	0.158

Table 23. Young's modulus of waste tyre rubber concrete.

S.No	Mix	Young's Modulus(N/mm ²)
1	A4-4	27.12x103
2	A4-4-4	28.3x103
3	B4-4	24.79x103
4	B4-4-4	12.43x103

Graphical presentation of experimental results

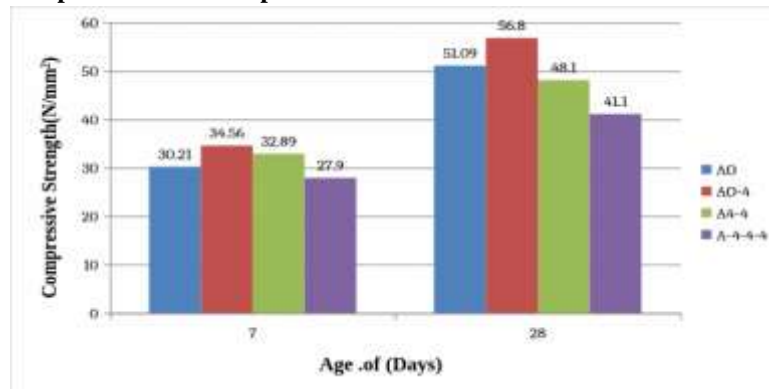


Fig. 4.1 Variation of Compressive strength with Waste tyre rubber content -M40 concrete

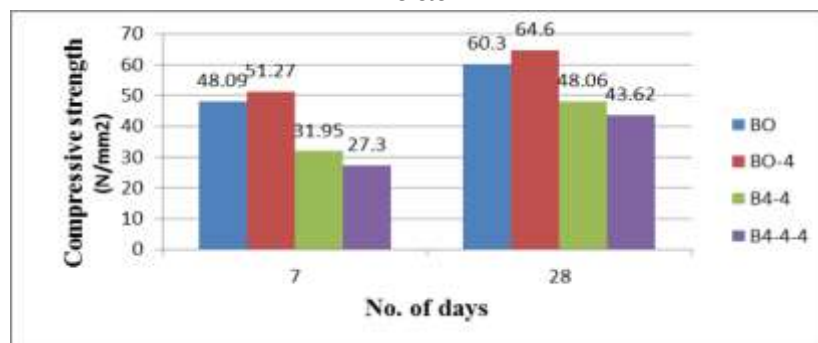


Fig. 4.2 Variation of compressive strength with Waste tyre rubber content –M70 concrete

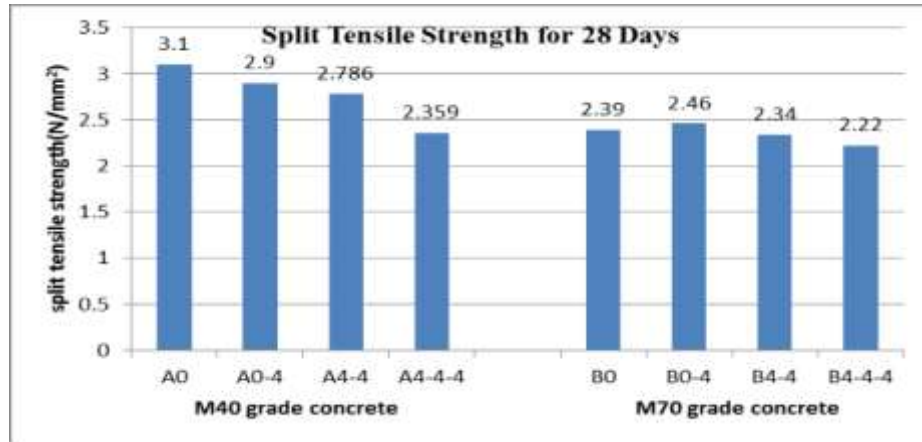


Fig. 4.3 Variation of Split Tensile Strength with Waste tyre rubber content - M40 & M70 Concrete

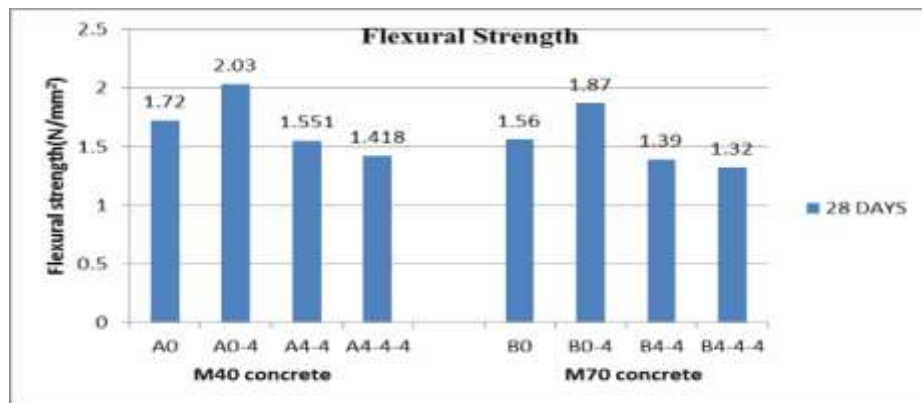


Fig. 4.4 Variation of Flexural Strength with Waste tyre rubber content -M40&M70 concretes

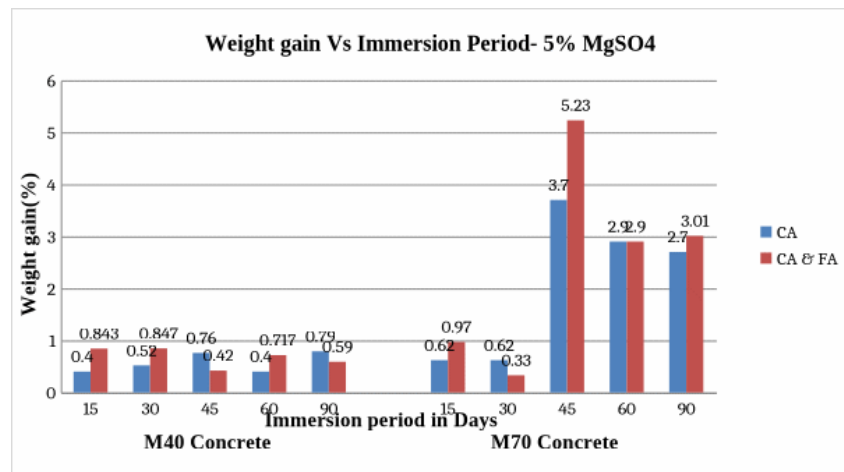


Fig. 4.5 Variation of weight gain with immersion period

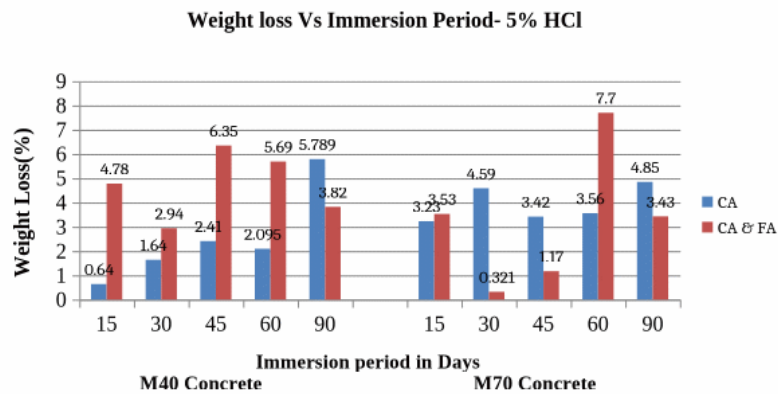


Fig. 4.6 Variation of weight loss with immersion period

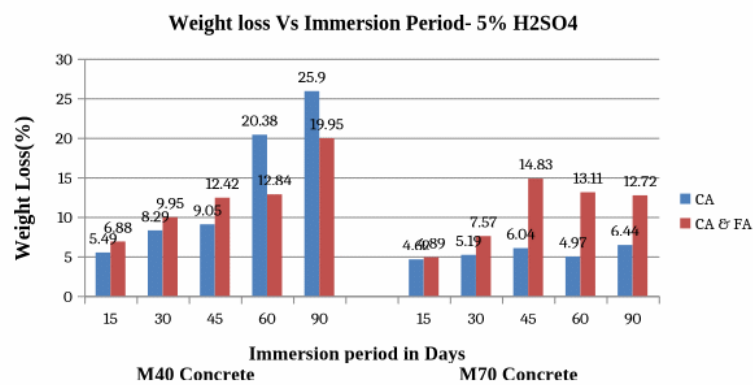


Fig. 4.7 Variation of weight loss with immersion period

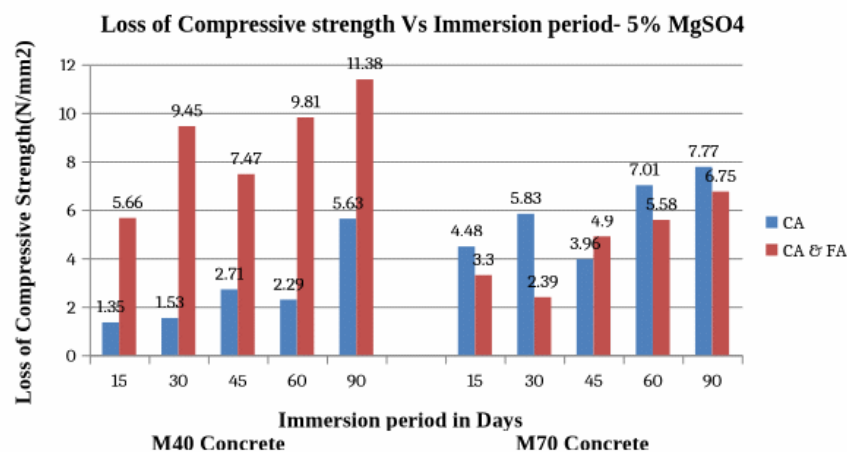


Fig. 4.8 Variation of Percentage of Strength loss when immersed in acid (MgSO₄)

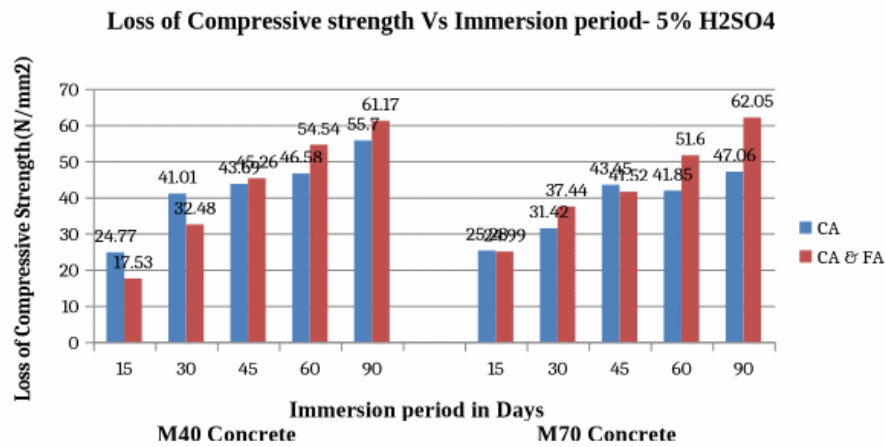


Fig. 4.9 Variation of Percentage of Strength loss when immersed in acid(H₂SO₄)

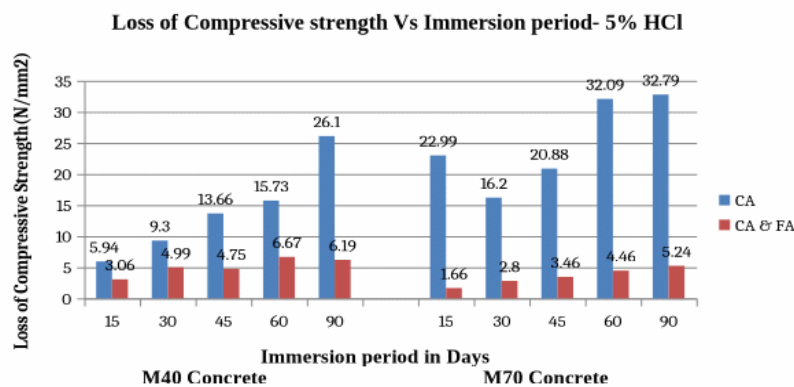


Fig. 4.10 Variation Percentage of Strength loss with immersed in acid(HCl)

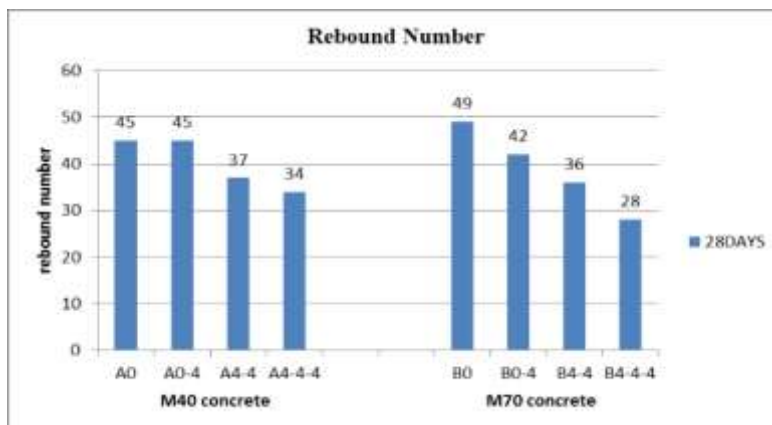


Fig. 4.11 Variation of Rebound Number with Waste tyre rubber content

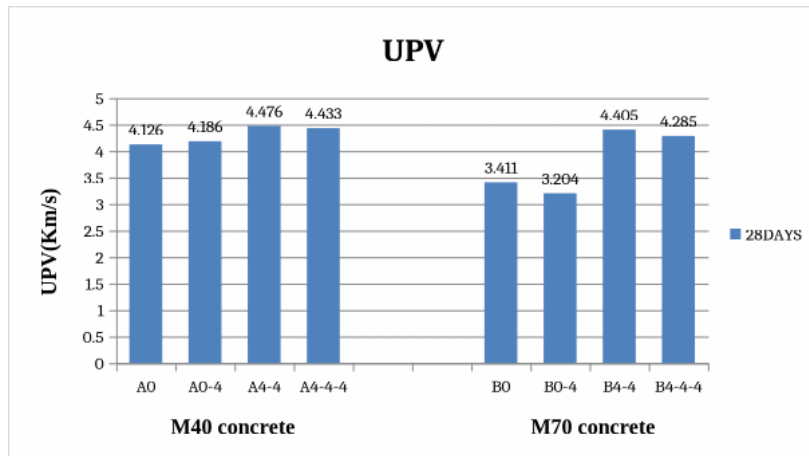


Fig. 4.12 Variation of UPV with Waste tyre rubber content

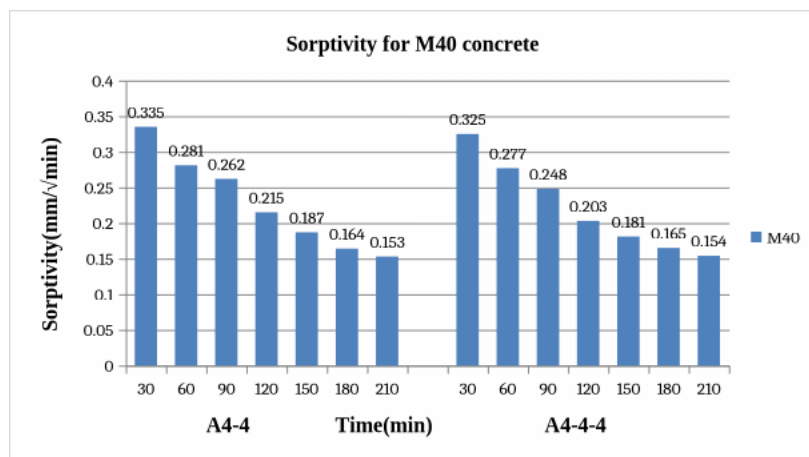


Fig. 4.13 Variation of Sorptivity with time using Waste tyre rubber content-M40 concrete

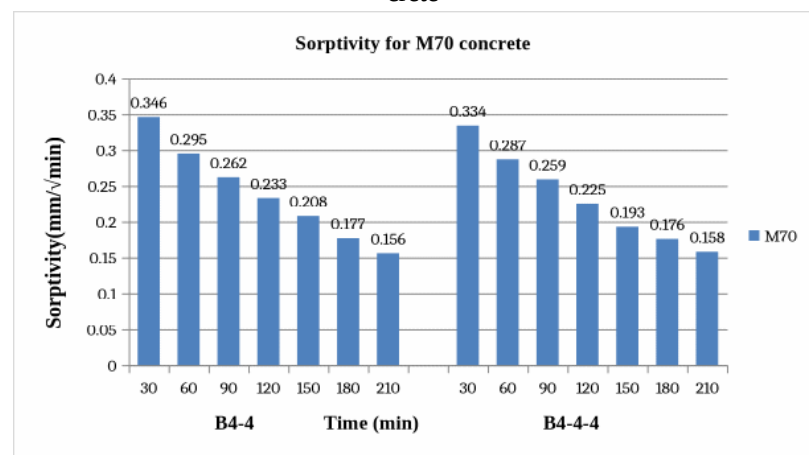


Fig. 4.14 Variation of Sorptivity with time using Waste tyre rubber content –M70 concrete

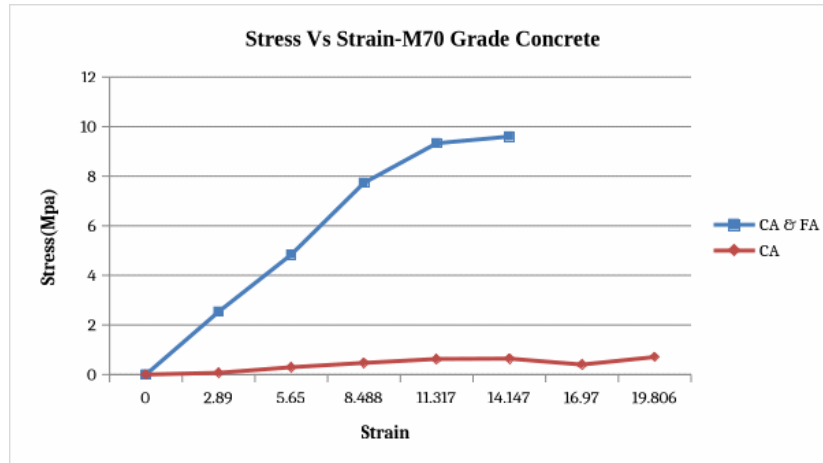


Fig.4.15 Stress – Strain behaviour of M70 Concrete

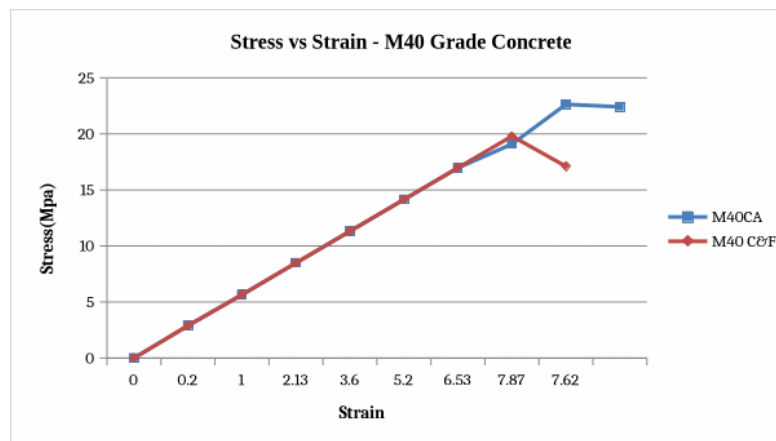


Fig. 4.16 Stress – Strain behaviour of M40 Concrete

Interpretation of results

Fig 4.1 & 4.2 represents the variation of 7 & 28 day compressive strength with waste tyre rubber content for M40 and M70 grade concretes. The values of 7 days and 28 day compressive strengths of casted cubes for M40 grade & M70 concretes are also shown in Tables 4.3 & 4.4. The strength values reported are the average of three test cubes.

Fig 4.3 represents the variation of split tensile strength with the waste tyre rubber content for M40 & M70 grade concretes. The values of 28 day split tensile strengths of cast cylinders for both M40 & M70 grade concretes are also shown in Tables 4.5 & 4.6. The strength values reported are the average of three cylinders.

Fig 4.4 represents the variation of 28 days flexural strength with waste tyre rubber content (%) in M40 and M70 grade concretes. The values of flexural strengths of are cast prisms of M40 and M70 grade concretes are also presented Tables 4.7 & 4.8.



Fig 4.5 & 4.8 depict the variation of change of mass with immersion period in 5% solution of $MgSO_4$. It was noticed that there was a slight increase in the mass of specimens due to the absorption of the exposed liquid. The increase in mass of specimens soaked in magnesium sulphate solution was approximately 0.79%, 0.59% for M40 (A4-4 & A4-4-4) and 2.7%, 3.01% for M70 (B4-4 & B4-4-4) after 90 days of exposure.

Fig 4.8 depicts the variation of compressive strength of rubber concrete exposed to $MgSO_4$ for different periods of 15, 30, 45, 60, and 90 days. The loss of compressive strength in acid curing, were found to be 1.35%, 1.53%, 2.71%, 2.29%, 5.63% & 5.66%, 9.45%, 7.47%, 9.81%, 11.38 for M40 (A4-4 & A4-4-4) and 4.48%, 5.83%, 3.96%, 7.01%, 7.77% & 3.30%, 2.39%, 4.90%, 5.58%, 6.75% for M70 (B4-4 & B4-4-4) respectively when they were immersed in $MgSO_4$ solution for different periods of 15, 30, 45, 60 and 90 days. Therefore it can be observed specimens have more resistance to sulphate attack.

Fig 4.6, 4.7, 4.9 & 4.10 depicts the variation of change of mass with immersion period in 5% solution of H_2SO_4 and HCl. It was noticed that there is decrease in mass after immersion in both H_2SO_4 and HCl solution. This is due to, the concrete was eaten by acid. The % loss of mass on 90 days exposure to 5% solution H_2SO_4 and HCl were found to be 25.9%, 19.95% and 5.789%, 3.82% for M40 (A4-4 & A4-4-4) and 6.44%, 12.72% and 4.85%, 3.43% for M70 (B4-4 & B4-4-4) respectively.

Fig 4.10 depicts the variation of compressive strength of rubber concrete when exposed to 5% H_2SO_4 for different immersion periods of 15, 30, 45, 60, and 90 days. The loss of compressive strength in respected specimens were found to be 55.70%, 61.17% for M40 (A4-4 & A4-4-4) and 47.06%, 62.05%, for M70 (B4-4 & B4-4-4) respectively when they were immersed in H_2SO_4 solution 90 days.

Fig 4.9 depicts the variation of compressive strength of rubber concrete when exposed to 5% HCl for different immersion periods of 15, 30, 45, 60, and 90 days. The loss of compressive strength of the specimens were found to be 26.10%, 6.19% for M40 (A4-4 & A4-4-4) 32.79%, 5.24% for M70 (B4-4 & B4-4-4) respectively when they were immersed in HCl solution for 90 days. Therefore it can be observed that hydrochloric acid immersed specimens are more resistance to acid attack than the sulphuric acid immersed specimens.

Fig 4.11 depicts the variation of rebound number with waste tyre rubber content for M40 and M70 grade concretes. The values of rebound number for M40 grade and M70 concretes are as given in Tables 4.13.

Fig 4.12 depicts the variation of ultrasonic pulse velocity with waste tyre rubber content (%) for M40 and M70 grade concretes. The values of ultrasonic pulse velocity for M40 and M70 grade concretes are also shown in Tables 4.14.



Fig:4.13 and Fig:4.14 represent the variation of Sorptivity with time for M40 grade and M70 concretes. The Sorptivity values for M40 grade and M70 concretes are also shown in Tables 4.15 and 4.16. It may be noticed that the Sorptivity of concrete depends on the fineness of the material, pozzolonic activity and richness of the mix.

Effect of Waste tyre rubber content (%) on stress-strain behaviour and modulus of Elasticity/ Young's modulus (E) of concrete.

V. Conclusions

1. Workability of waste tyre rubber concrete decreases with increase in waste tyre rubber in both M40 grade & M70 grade concretes because waste tyre rubber particles absorb more water as compared to fine aggregate.
2. The target mean strength was obtained for rubberised concrete using 4% coarse aggregate rubber and 4% silica fume.
3. The required target mean strength could not be achieved for M70 grade concrete due to poor bond strength between the cement paste and the rubber tyre aggregates.
4. Rebound number of 28days cured concrete has been optimum with 4% replacement of conventional coarse & fine aggregate, coarse aggregate with waste tyre rubber in both M40 and M70 grade concretes.
5. M40 grade concrete, concrete with 4% and 8% waste tyre rubber indicated "good" quality with UPV values ranges from 3510-3750 m/sec while the control mix in M70 concrete, was also found to be "good" quality.
6. The control mix & concrete with 4% waste tyre rubber in M40 grade concrete indicated "medium" quality with UPV values ranging from 3020-3260m/sec, while the values of M70 concrete with waste tyre rubber indicates "medium" quality. While the control mix of M40 grade concrete was also found to be "medium" quality.
7. Sorptivity of waste tyre rubber concrete increased with increase in waste tyre rubber content and has been minimum for 4% replacement of coarse & fine aggregate, coarse aggregate with waste tyre rubber in both M40 grade & M70 concretes indicating that concrete of 4% waste tyre rubber is less permeable.
8. In M40 & M70 grade concrete the young's modulus of rubber concrete are very less and young's modulus of m40 grade is more than M70 grade concrete.
9. The rubber concrete UPV and Rebound Number decreases by increasing the rubber content.
10. Strength decreases with increasing rubber content.

VI. Scope for Further Investigation

1. Investigations can be carried out by replacing natural fine aggregate with different proportions of recycled fine aggregate and waste tyre rubber.
2. Investigations can be further carried out with different percentages of replacement of fine aggregate with crumb rubber using various admixtures.



3. Investigations can be further carried out for durability properties such as carbonation depth, chloride penetration test and so on.
4. Studies can be further carried out with different treatments on crumb rubber.

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