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Significance of Silica Fume and Glass Fiber on the Mechanical Properties of Recycled Aggregate Concrete

N. Vinay Kumar[1], P. S. S. Anjaneya Babu[2]

[1]PG Student, Department of Civil Engineering, Gudlavalleru Engineering College, India
[2]Assistant Professor, Department of Civil Engineering, Gudlavalleru Engineering College, Andhra Pradesh, India

Abstract: ***Construction and infrastructure are the fastest growing industries and concrete is the second highest used resource in today's scenario after water which leads to huge quantities of C&D waste (construction and demolition). This creates a significant problem because of the difficulties associated with managing the increased volume of concrete waste. The various studies related to sustainable concrete construction have encouraged recycled aggregate which is a Replacement of natural aggregate in concrete mixes. As a result, use of recycled aggregate it can reduce the amount of landfill as well as requirement of virgin aggregate. In this experimental study the natural coarse aggregate is replaced with 0%, 25%, 50%, 75%, and 100%, with recycled coarse aggregate. The strength of concrete decrease with increase in the percentage of recycle aggregate, this is due to improper bonding between the cement paste and aggregate. The significance of silica fume in concrete mix will improve the bonding and quality of recycled aggregates in concrete. The percentage of partial replacement will be 0%, 10%, 15%, with silica fume. And also to increase the tensile strength of concrete we use glass fibers with different percentages 0.005%, 0.015% and 0.025%. Concrete specimen will be casted with Triple mixing method (TM). In this experiment concrete made with silica fume with partial replacement of cement, Glass Fibers are added to the cement and recycled coarse aggregate as Replacement of natural coarse aggregate will be studied to improve the workability, compressive strength, and tensile strength. In this study, the mixing of concrete is done by triple mix method. With silica fume as an admixture recycled aggregate concrete of M35 grade will be manufactured and tested for physical and mechanical properties. These strength results obtained is compared with conventional concrete results. The target strength is achieved in compression at 12.5% replacement of silica fume, 0.005% addition of S-Glass fibers and also in tension at 12.5% replacement of silica fume, 0.015% addition of S-Glass fibers.***

Keywords: Recycled aggregate, recycled coarse aggregate concrete, Silica fume, Glass fiber, Compressive strength, Split tensile strength

1. Introduction

Construction and Infrastructure industries have made a huge difference with regards to development in today's world and we need to mention 'concrete' in our context as a key material for these industries. Concrete is basically a uniform mixture of various materials which glue together to form a hard and durable compound. Cement, Fine aggregates Coarse aggregates and water are basic components required to generate a conventional concrete mix and any other mineral or material added to the mix apart from these components are called admixtures. Discussing about the components here's some data about what actually concrete comprises are cement which is the binder in the mix which is manufactured using lime stone as the raw material, the coarse aggregates are generally quarried from mines and for fine aggregates are quarried and transported from river beds. The quarried rocks are crushed and sieved to desired sizes. The 4/5th part of concrete comprises of the aggregates.

We derive all the raw material required to generate a conventional concrete mix from quarrying and mining. In near future we wouldn't have raw materials to generate concrete with reference to rate of concrete quantity being used. Since these raw materials are nonrenewable, the precautions should be taken to preserve them. Here we have "Recycled Aggregates" as a terrific solution in our construction methods.

From the demolished waste of building, kerbs, pavements and other constructions debris is obtained. From debris aggregates are extracted using chemical or mechanical methods in order to reuse in low and medium strength concrete as a replacement for natural aggregates. By this we can reduce the land fill area due to Construction and demolition (C&D) materials wastes and also save natural resources.

The pozzolanic material used in the experiment is Silica fume which is 10 times finer than cement particles. In concrete a layer is formed between the cement paste and the aggregates this layer is termed Interfacial transition zone (ITZ).The thickness of layer is based on size of aggregate and due to heat of hydration the water evaporates from ITZ and pores are formed reducing the bonding strength of concrete hence silica fume helps in filling the pores in ITZ since its finer than cement and this is what generally happens in concrete but in concrete where RCA is used strength is further reduced due to the high water absorption by the adhered mortar and when the aggregates are pre-coated in the mixing methods using silica fume the pores in the adhered mortar are occupied by Silica fume hence reducing water absorption. So we see that silica fume improves the properties of recycled aggregate and also strengthens the concrete by improving microstructure of concrete.

Many Researches concentrate only compressive strength but structure failure in Tensile strength. To use of glass fibers to improve the tensile strength.

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In this study the various percentages of recycled aggregate were added to coarse aggregates, 0%,10%, 12.5% & 15 % of silica fume is replaced with cement and 0.005%,0.015%& 0.025% 0f S-Glass Fibers are addition to cement . The compressive strength and split tensile strength are observed.

2. Materials

2.1 Cement

Ordinary Portland cement of 53 grade conforming to IS: 12269-1987 was used for this entire study.

Table 1: Tests on Cement

S. No.	*Property*	*Value Obtained Experimentally*	*Value as per IS: 1489-1991*
1.	Normal Consistency	28%	-
2.	Fineness of cement	0.5	Min 0.1
3.	Setting time Initial setting time Final setting time	42min 450min	Min 30 minutes Max 600 minutes
4.	Specific gravity	3.11	3.15

2.2 Fine Aggregate

Locally available river sand passing through IS sieve 4.75mm was used as fine aggregate and the following tests were carried out on a sand as per IS 2386- 1986 (part 3).

Table 2: Tests on Fine Aggregate.

S. No	*Particulars of test*	*Test results*
1	Specific gravity	2.61
2	Fineness modulus	2.5
3	Water absorption (%)	1.8
4	Sieve analysis	Zone II

2.3 Coarse Aggregate

For this study, two types of coarse aggregates were used for the preparation of concrete i.e. Natural coarse aggregate (NCA) and Recycled coarse aggregate (RCA). Both NCA and RCA aggregates were screened into two different size fractions (i.e. 70% of 20mm to 16mm sized and 30% of 12mm to 10mm sized) and combined to form NCA & RCA.

2.3.1 Natural coarse aggregate

For this study, locally available crushed stone aggregate of size 20mm were used and the following tests were carried out on NCA.

Table 3: Tests on Coarse Aggregate

S. No	*Particulars of test*	*Test results*
1	Type	Crushed
2	Specific gravity	2.76
3	Fineness modulus	3.32
4	Water absorption	1.58%

2.3.2 Recycled Aggregate (RCA)

Recycled aggregate were prepared by crushing the M35 grade manufactured cubes. The cubes were cured for 28 days and broken into smaller pieces by hammer then sieved to collect maximum size of 20mm and minimum size of 10mm. The following tests were carried out on RCA.

Figure 1: Recycled coarse aggregate

Table 4: Tests on RCA

S. No	*Particulars of test*	*Test results*
1	Specific gravity	2.61
2	Fineness modulus	3.57
3	Crushing value (%)	17.23
4	Impact value (%)	20.61

2.4Water

In this study portable water conforming to IS: 456-2000 was used for casting and curing.

2.5 Silica fume

Silica fume is a byproduct of the industrial manufacture of ferrosilicon alloys and silicon metabolism high temperature electric arc furnaces. The use of silica fume helps in filling concrete pores resulting in improved impermeability of concrete.

Figure 2: Silica Fume

The chemical composition and physical properties of silica fume are as follows:

Table 5: The chemical composition of silica fume

Components	*Silica fume*
Silica (SIO_2)	99.886%
Alumina (AI_2O_3)	0.043%
Ferric Oxide (Fe_2O_3)	0.040%
Titanium Oxide (TiO_2)	0.001%
Calcium Oxide (CaO)	0.001%
Magnesium Oxide (MgO)	0.000%
Pottasium Oxide (K_2O)	0.001%
Sodium Oxide (Na_2O)	0.003%
Loss On Ignition	0.015%

Table 6: The physical properties of silica fume

Physical Properties	*Results*
Physical State	Micronized powder
Odour	Odorless
Appearance	White colour powder
Colour	White
Pack Density	0.76 gm/cc
pH of 5% Solution	6.90
Specific Gravity	2.63
Moisture	0.058%
Oil Absorption	55ml/100 gms

2.6 Glass Fiber

High strength glass made with magnesium alumina silicates. Used where high strength, high stiffness, extreme temperature resistance, and corrosive resistance is needed.

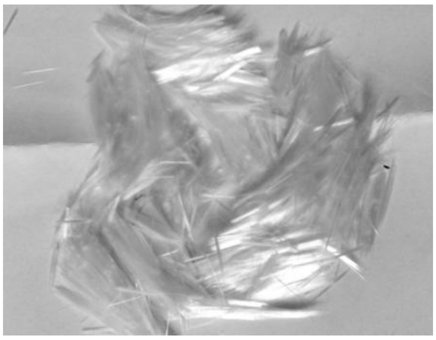

Figure 3: S- Glass Fibers

Table 7: Properties of S-Glass Fibers

Fiber Type	S-Glass fiber
Density (gm/cm3)	2.53
Elastic Modulus (Gpa)	89
Tensile Strength (Mpa)	4600
Diameter In Microns	10
Length In mm	6
Percent Elongation	5.2

3. Mix Design

Concrete mix proportions were designed as per IS 10262:2009 code. A super plasticizer of SP430 was used for high degree of workability. The content of super plasticizer was 0.9% of cement used. The resulting concrete is proportioned for M35 grade as per nominal mix design. The natural coarse aggregate is replaced by recycled coarse aggregate in percentages i.e., 0%, 25%, 50%, 100% and these specimens were tested for compression and split tensile strengths.

The variations of compressive strength and split tensile strength without RCA and with RCA are discussed in the result section. The table 8 shows the Concrete mix proportions were designed as per IS: 10262-2009 code for M35.

Table 8: Mix Proportion

Cement (Kg/m^3)	*Fine aggregate (Kg/m^3)*	*Coarse aggregate (Kg/m^3)*	*Water content (Kg/m^3)*
385.185	808.157	1125.896	171.852

3.1 Mix Proportions

Here three mixes of concrete were prepared i.e., without RCA(Mix 1);with RCA, replacement of silica fume by 12.5% and 0.005% addition of S-Glass fibers (Mix 2); 12.5% 0f silica fume and 0.015% (Mix 3). The water-cement ratio is 0.44. To increase the workability of recycled aggregate concrete super plasticizer (SP 430). When super plasticizer (SP430) is used the water-cement ratio is 0.43. The crushed aggregates are used for the replacement of natural aggregates in different proportions such as 0%, 25%, 50%, 75%, and 100%.Tables 9,10 and 11 shows the mix proportions of recycled aggregate concrete with 12.5% silica fume.

Table 9: Mix Proportion without RCA, different % of silica fume and S-Glass fiber

S. No.	*%Silica Fume(replacement Of Cement)*	*S-glass Fibers*	*Mix proportions(Kg/m³)*					
			Cement	*Silica fume*	*FA*	*NCA*	*S-glass Fibers*	*Water*
1.	0%	0.005%	385.185	0	808.157	1125.896	0.0192	171.852
		0.015%	385.185	0	808.157	1125.896	0.0577	171.852
		0.025%	385.185	0	808.157	1125.896	0.0962	171.852
2.	10%	0.005%	346.666	38.518	808.157	1125.896	0.0192	171.852
		0.015%	346.666	38.518	808.157	1125.896	0.0577	171.852
		0.025%	346.666	38.518	808.157	1125.896	0.0962	171.852
3.	12.5%	0.005%	337.036	48.148	808.157	1125.896	0.0192	171.852
		0.015%	337.036	48.148	808.157	1125.896	0.0577	171.852
		0.025%	337.036	48.148	808.157	1125.896	0.0962	171.852
4.	15%	0.005%	327.407	57.777	808.157	1125.896	0.0192	171.852
		0.015%	327.407	57.777	808.157	1125.896	0.0577	171.852
		0.025%	327.407	57.777	808.157	1125.896	0.0962	171.852

Table 10: Mix Proportion with RCA, 12.5% replacement of silica fume and 0.005% addition of S-Glass fibers

RAC Mix	*Source of RCA*	*% replacement (RCA)*	*Mix proportions(Kg/m³)*						
			Cement	*Silica fume (12.5%)*	*S-Glass fibers (0.005%)*	*FA (Sand)*	*NCA*	*RCA*	*Water*
M35	M35 (RAC 35)	25	337.036	48.148	0.0192	808.157	844.422	281.474	168.385
		50	337.036	48.148	0.0192	808.157	562.948	562.948	168.385
		75	337.036	48.148	0.0192	808.157	281.474	844.422	168.385
		100	337.036	48.148	0.0192	808.157	0	1125.896	168.385

Table 11: Mix Proportion with RCA, 12.5% replacement of silica fume and 0.015% addition of S-Glass fiber

RAC Mix	*Source of RCA*	*% replacement (RCA)*	*Mix proportions(Kg/m³)*						
			Cement	*Silica fume (12.5%)*	*S-Glass fibers (0.015%)*	*FA (Sand)*	*NCA*	*RCA*	*Water*
M35	M35 (RAC 35)	25	337.036	48.148	0.0577	808.157	844.422	281.474	168.385
		50	337.036	48.148	0.0577	808.157	562.948	562.948	168.385
		75	337.036	48.148	0.0577	808.157	281.474	844.422	168.385
		100	337.036	48.148	0.0577	808.157	0	1125.896	168.385

3.2 Mixing Procedure

Mixing of ingredients is done in pan mixer of capacity 50 liters. The cementations materials are thoroughly blended and then the aggregate is added and mixed followed by gradual addition of water and mixing. Wet mixing is done until a mixture of uniform colour and consistency are achieved which is then ready for casting. Before casting the specimens, workability of the mixes was found by slump cone test.

There are 3 types of mixing methods;
a) Normal mixing method
b) Double mixing method
c) Triple mixing method

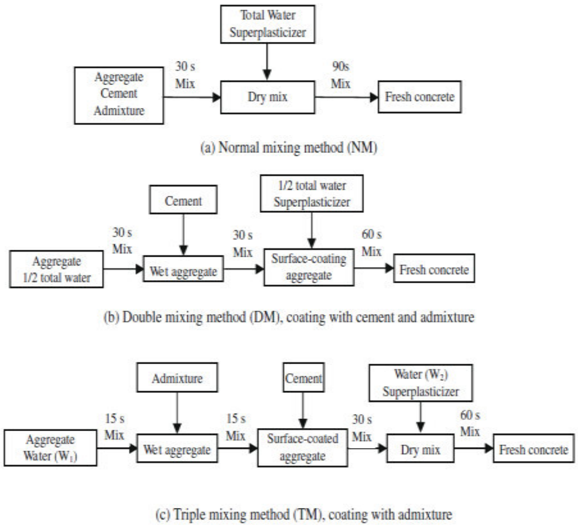

Figure 4: Mixing Methods

3.1.1 Triple Mixing Method(TM)

The mixing methods used in the study are illustrated in Figure4. The triple mixing method (TM) was designed as follows:

Concrete mixes were designed with free water cement ratio of 0.42 and the free water content (W_f) in all concrete mixes was 210 Kg/m^3. The water adsorbed by the coarse and fine aggregates was included in the total water content (W_t).

The coarse and fine aggregates were mixed for 15 seconds with addition of a certain amount of water (W_1) to obtain wet aggregates. Then the admixture used was added to the wet aggregates and agitated for another 15 seconds to get the aggregates surface-coated with admixture and the cement was then added and mixed for further 30 seconds. Finally, the rest water W_2 together with the superplasticizer used was added for the last 60 seconds mixing.

Here,
$W_1$is calculated as $W_1 = 1.2(W_t - W_f)$ and
$W_2$is calculated as $W_2 = W_t - W_1$

4. Results and Discussions

4.1 Compressive Strength

The experimental results obtained after the curing of 7 days and 28 days are shown in the table 12 & 13. Figures 5, 6, 7 & 8 represent the compressive strength for 7 days &28 days without RCA and Figure 9 represent the compressive strength for 7 days &28 days Replacement of RCA (0% to 100%) with 12.5%silica fume and 0.005% S-Glass fibers. The compressive strength is decreased with the increase in percentage of recycled aggregates. At 28 days 100% replacement of RCA with addition of silica fume achieves strength of 39.43MPawhere as target mean strength of M35is 43.25MPa. In short period of time this strength can exceed to the strength of natural aggregate concrete.

Table 12: Compressive strength for 7 and 28 days without RCA

S. No.	*%Silica Fume(replacement Of Cement)*	*S-glass Fibers*	*Compressive Strength (Mpa)*	
			7days	*28days*
1.	Nominal Mix		27.39	44.32
2.	0%	0.005%	27.41	44.40
		0.015%	28.53	45.36
		0.025%	27.65	44.61
3.	10%	0.005%	28.67	45.43
		0.015%	28.93	45.92
		0.025%	28.72	45.61
4.	12.5%	0.005%	30.13	47.39
		0.015%	29.55	46.61
		0.025%	29.24	46.33
5.	15%	0.005%	27.63	45.12
		0.015%	27.55	44.83
		0.025%	27.32	44.29

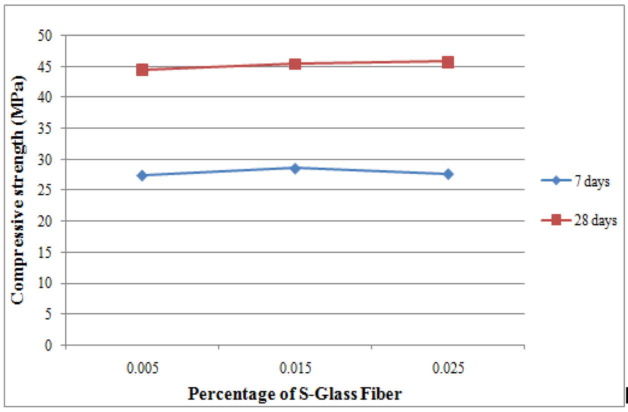

Figure 5: Compressive strength for 7 and 28 days 0% SF without RCA

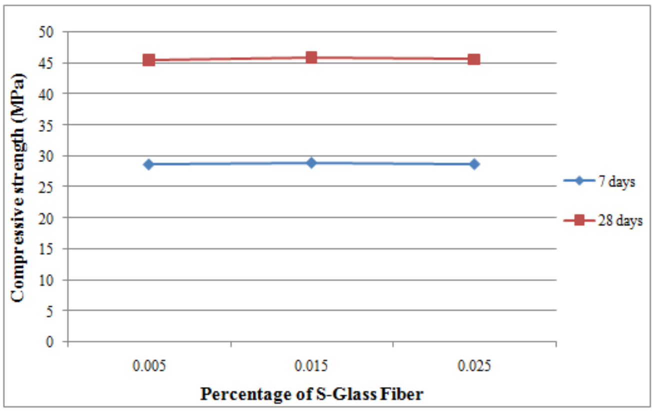

Figure 6: Compressive strength for 7 and 28 days 10% SF without RCA

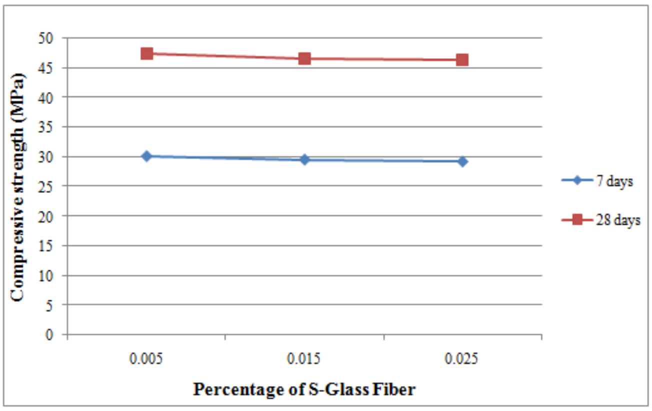

Figure 7: Compressive strength for 7 and 28 days 12.5% SF without RCA

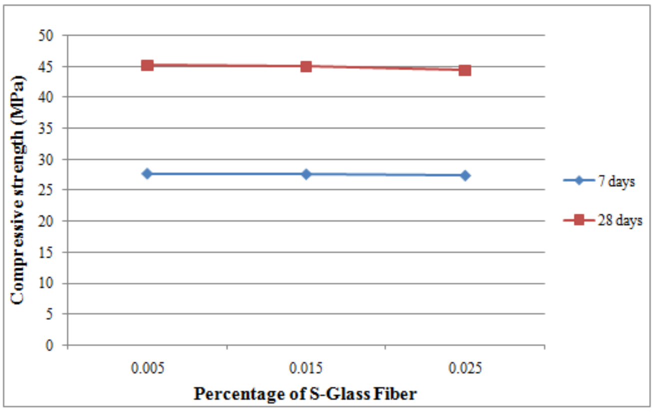

Figure 8: Compressive strength for 7 and 28 days 15% SF without RCA

Table 13: Compressive strength for 7 and 28 days with RCA

Optimum		*% of*	*Compressive Strength(Mpa)*	
Silica fume	*S-Glass fibers*	*RCA*	*7 days*	*28 days*
12.5%	0.005%	0	31.32	47.5
		25	30.27	46.36
		50	29.08	45.73
		75	27.82	42.16
		100	25.62	39.43

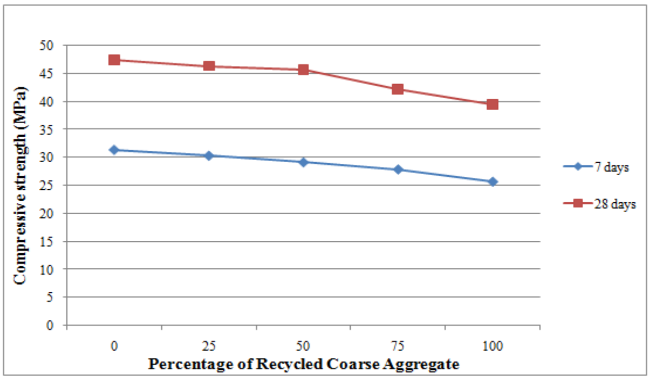

Figure 9: Compressive strength for7 days and 28 days with 0% to 100%RCA, 12.5% SF and 0.005% GF

4.2 Split Tensile Strength

The split tensile strength results obtained after the curing of 7 days and 28 days are shown in the table 14 & 15. Figures 10, 11, 12, 13 represent the split tensile strength for 7 days &28 days without RCA and Figure 14 represent the split tensile strength for 7 days &28 days Replacement of RCA (0% to 100%) with 12.5%silica fume and 0.015% S-Glass fibers. The split tensile strength of the three sets is also decreased with the increase in percentage of recycled aggregates. The split tensile strength also shows the similar pattern of results as the compressive strength results.

Table 14: Split Tensile strength for 7 and 28 days without RCA

S. No.	*%Silica Fume(replacement Of Cement)*	*S-glass Fibers*	*Tensile Strength (Mpa)*	
			7days	*28days*
1.	Nominal Mix		3.12	4.17
2.	0%	0.005%	3.19	4.26
		0.015%	3.22	4.30
		0.025%	3.18	4.25
3.	10%	0.005%	3.24	4.33
		0.015%	3.26	4.36
		0.025%	3.23	4.31
4.	12.5%	0.005%	3.29	4.39
		0.015%	3.42	4.56
		0.025%	3.31	4.42
5.	15%	0.005%	3.24	4.32
		0.015%	3.22	4.30
		0.025%	3.19	4.26

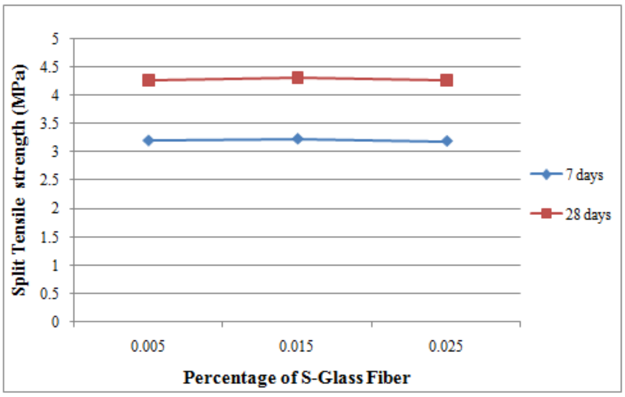

Figure 10: Split Tensile strength for 7 and 28 days 0% SF without RCA

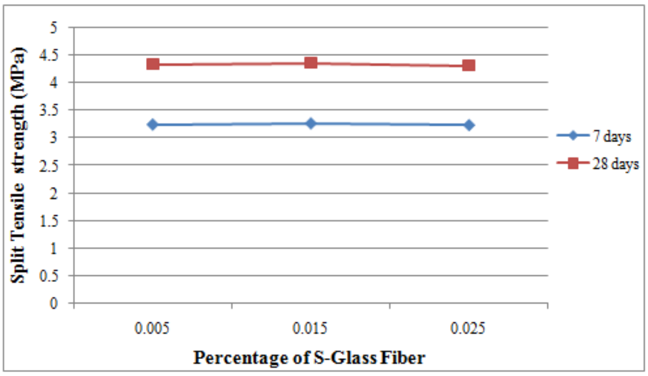

Figure 11: Split Tensile strength for 7 and 28 days 10% SF without RCA

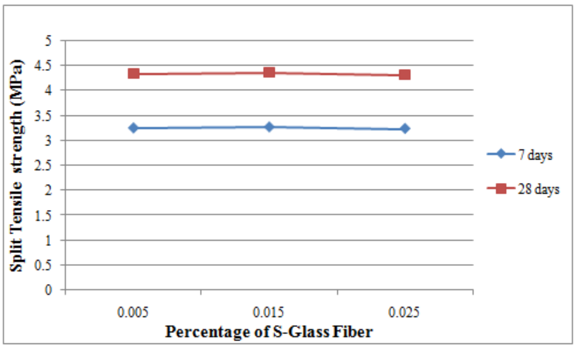

Figure 12: Split Tensile strength for 7 and 28 days 12.5% SF without RCA

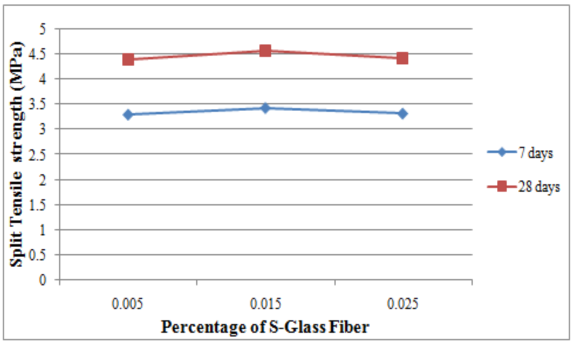

Figure 13: Split Tensile strength for 7 and 28 days 15% SF without RCA

Table 15: Split Tensile strength for 7 and 28 days with RCA

Optimum		*% of*	*Split Tensile Strength (Mpa)*	
Silica fume	*S-Glass fibers*	*RCA*	*7 days*	*28 days*
12.5%	0.015%	0	3.54	4.63
		25	3.26	4.35
		50	3.01	4.09
		75	2.82	3.96
		100	2.65	3.83

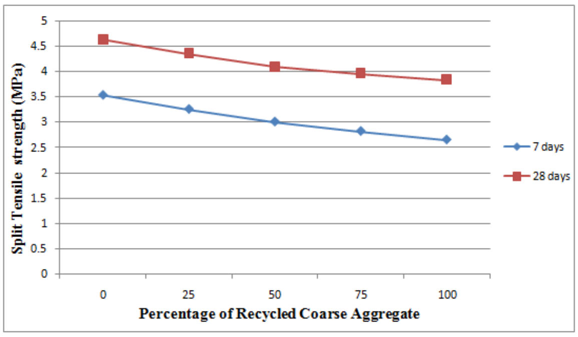

Figure 14: Split Tensile strength for7 days and 28 days with 0% to 100%RCA, 12.5% SF and 0.015% GF

5. Conclusions

The following conclusions are made from the study:

1) The compressive strength of recycled concrete is decreases when the natural aggregates are replaced with recycled coarse aggregate by 25, 50, 75 and 100% respectively, because of the loose mortar around the recycle aggregate which do not allow the proper bonding between the cement paste and aggregate.
2) It is concluded that without decreasing the water-cement ratio, the target mean strength of above mentioned grade of concrete can be achieved through recycled aggregates and Silica fume.
3) For 12.5% replacement of silica fume in cement the strength value increases when compared to 15% of silica fume.
4) At 28 days 100% replacement of RCA with addition of silica fume achieves strength of 39.43 MPa.
5) The split tensile strength value is maximum with the addition of S-Glass Fibers at 0.015%.

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