IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 17, Issue 1 Ser. II (Jan - Feb 2020), PP 13-21
www.iosrjournals.org

The Effect of Using Waste Glass [WG] As Partial Replacement of Coarse Aggregate on Concrete

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Abstract: *In this study, (WG) was used as partial replacement of basalt (coarse aggregate) with 0%,5%,10%,15% ,20%, 25%,30%,35%,40%,45% and 50% ratios by weight. Some mechanical and other concrete properties produced in this way have been explored at both hardened and fresh stages. The results from the tested specimens (which prepared from concrete mixes with water/cement ratio equals to 0.5), illustrated that the usage of WG as a coarse aggregate resulted in reduction in slump, density, and water absorption, as well as enhancement the strength of concrete ([compression and tension]) until 25% of replacement by weight. Tests showed that with the percentage increase of WG the strengths gradually increase up to a given limit beyond which they decrease. The maximum influence reached a 25% replacement ratio, where the strength growth [tension and compression) was approximately 15 % and 14 % respectively compared to the control concrete (0% WG).*

Keywords*: Concrete, Waste Glass, Coarse Aggregate, Slump, Compressive Strength*

Date of Submission: 10-01-2020 Date of Acceptance: 27-01-2020

I. Introduction

Concrete comprises three boss fixings (aggregate, cement, and water). The proportion and type of ingredients change the last item (concrete)properties. Coarse aggregate assumes a significant role in concrete creation, as it possesses around 33% of the concrete volume. The type of coarse aggregate goes a long way in defining the concrete quality **[1].** Following an ordinary development in the populace, the type and measure of waste materials have expanded. For hundreds of years, several of the non- decomposing waste materials stay in the environment. The waste disposal problem was caused by non-decomposing waste materials, thus contributing to the environmental crisis **[2].** Different industrial waste materials such as tiles waste aggregates from the destruction of structures, slag, fly ash, etc., have been attempted as extra material in concrete **[3].** The yearly local glass production and its usage are steadily increasing. This growth in using and production of glass in current years is owed to the growth in industrialization and the fast improvement in the standard of living. Due to this process, the accumulating quantities of WG, containing sheet or window glass, is a challenging problem, which needs active solutions. Hence, from an economical and environmental point of view, the recycled WG used in the production of original concrete has acquired growing importance in recent years. For several decades, efforts had been devoted to waste glass used in concrete **[4-5].** However, recently the WG has not been broadly utilized in the concrete mixes. The restricted use was due to the well-known problem of ASR (Alkali-Silica Reaction) caused by the reaction between silica that is contained in glass material and alkali in the cement. Many investigators **[6-21]** studied the WG used in plain concrete. Among the benefits of crushed WG used as aggregates in plain concrete is that glass absorption is almost zero, this creates a very durable material. Furthermore, glass has an ideal rigidity, and this provides concrete with high abrasion resistance. Many investigators **[1],[2],[3],[14]** show that the usage of WG as a coarse aggregate was possible. The waste glass was recycled in the coarse and fine particles form as normal aggregate. There are numerous efforts for the WG utilization in concrete in several forms, including coarse aggregates. Colored WG was recycled as coarse and fine aggregates to attain a great enhancement of concrete **[22].** It was found that waste glass used as coarse aggregate (with a 60% ratio) did not have an important effect upon the concrete workability and only a small decrease was reported in its strength **[23].** The usage of WG resulted in reducing the density and slump as the flexural, tensile and compressive strengths noticeably improved. With the increase of the WG ratio, the strengths gradually increase until a given limit and decrease thereafter. The ultimate effect was reached at the 25% replacement. At this ratio, the increases in the flexural, compressive and tensile strengths (at 28 days age) were 31%, 38%, and 30 %, respectively **[23].** The improvement possibility of the normal concrete strength over a level of WG percentages as a replacement for aggregate (coarse and fine) was investigated **[24].** It was found that the coarse WG ideal value to be used in the concrete about 0.25 (a water/cement ratio equals 0.4) **[24]**. In this study, the influence of WG used as a partial replacement of basalt (coarse aggregate) on the plain concrete properties was investigated

II. Materials

2.1 Cement

The cement used in this research was locally sourced conforming to the ESS 2421/2005 **[25].** The cement mechanical properties which were measured by laboratory tests indicated its reasonableness for concrete works. The chemical composition and mechanical properties of cement are given in Table [1] and Table [2].

Table [1] Cement properties

Properties	Results
Soundness(Le Chatelier) [mm]	0.95
Initial setting time [min]	96
Finial setting time [min]	157
Compressive strength[MPa] 3days	22.2
Compressive strength[(MPa] 28days	47.5

Table [2]Cement chemical composition

Composition	% By mass
Silica (SiO_2)	21.19
Alumina (Al_2O_3)	4.72
Iron oxide (Fe_2O_3)	3.05
Calcium oxide (CaO)	61.94
Magnesium oxide (MgO)	2.62
Sodium oxide (Na_2O)	0.28
Potassium oxide (K_2O)	0.84
Sulphur trioxide (SO_3)	3.92

2.2 Aggregate

In this experimental work,Local sand and basalt were used. The used basalt has a 25 mm maximum grain size.Properties of aggregate (coarse and fine)were investigated bythe ESS [Egyptian Standard Specifications] 1109/2002**[26]** and the outcomes are givenin Table [3].

2.3 Waste glass

In this research, the crushed WG was used as a coarse aggregate and Figure [1] illustrates the WG particle shape. It was brought from a glass factory wastes and pulverized in apparatus of coarse aggregates abrasion (Los Angeles). The sieves analysis test was carried out in the WG. The crushed WG used has a maximum size of 25 mm. The WG physical and chemical properties are presented in Table [3] and Table [4] respectively. The WG sieve analysis is given in Table [5].

Figure (1): Particles shape of coarse WG after sieve analysis

Table [3] Properties of basalt, sand and waste glass

Property	Sand	Basalt	Waste glass
Specific weight	2.70	2.69	2.31
Density [t/m3]	1.72	1.68	1.39
Water absorption%	1.23	0.40	0.20
Abrasion value %	-	24.20	27.5
Impact value %	-	28.50	31.7

Table [4] Chemical composition of waste glass

Composition	% by mass
Silica (SiO_2)	70.52
Alumina (Al_2O_3)	0.62
Iron oxide (Fe_2O_3)	0.71
Calcium oxide (CaO)	9.82
Magnesium oxide (MgO)	3.31
Sodium oxide (Na_2O)	12.95
Potassium oxide (K_2O)	0.28
Sulphur trioxide (SO_3)	---

Table [5] Sieve analysis data for coarse waste glass

Sieve Size (mm)	% Passing
25	100
20	90
14	72
10	30
5	2
2.36	0
1.18	0
0.60	0
0.30	0
0.15	0

2.4 Mixing water

For mixing, drinking water was used.

2.5 Superplasticizers

In the concrete mixture, the superplasticizer is considered a great water reducing agent. The superplasticizer used was from SIKA Company.

III. Experimental procedure

3.1. Mixture proportioning

Two types of concrete mixes were set up for this investigation. The plain concrete mixes, which consisted of sand (594 kg/m3), basalt (1188 kg/m3), cement (400 kg/m3), and water (200 kg/m3). The other concrete mixes were made of waste glass coarse aggregates of 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45% and 50% as partial replacement for coarse aggregate and with the same amounts of sand, cement, and water in the plain mixes. Likewise, a superplasticizer was utilized per m3 to keep the slump values between (6-11) cm. Both concrete mixes types were cured for 28 days. Table [6] shows the concrete mixes proportion.

Table [6] Concrete mixes proportion

Mix no	Waste Glass %	Waste Glass kg/m^3	Cement kg/m^3	Water kg/m^3	Basalt kg/m^3	Sand kg/m^3	Super plasticizer kg/m^3
1	0%	0	400	200	1188	594	4.8
2	5%	59.4	400	200	1128.6	594	4.8
3	10%	118.8	400	200	1069.2	594	4.8
4	15%	178.2	400	200	1009.8	594	4.8
5	20%	237.6	400	200	950.4	594	4.8
6	25%	297	400	200	891	594	4.8
7	30%	356.4	400	200	831.6	594	4.8
8	35%	415.8	400	200	772.2	594	4.8
9	40%	475.2	400	200	712.8	594	4.8
10	45%	534.6	400	200	653.4	594	4.8
11	50%	594	400	200	594	594	4.8

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3.2. Casting and curing of test specimens

As indicated by B.S.1881:1952 **[27]** casting, compaction and curing were done. Tests were conducted on fresh concrete to determine the slump. For the compressive strength determination at 28 days three cubes (15cm length) were cast for each concrete mixes, also for indirect tensile strength, three cylinders (30cm height and 15 cm diameter) were cast.

3.3. Testing of specimens

3.3.1. Slump test

This was achieved by BS 12350-2:2009 **[28]**.To determine the concrete workability, a slump test was conducted on fresh concretes. The concrete workability is influenced by consistency (drier mixes, which are less workable than wetter mixes).

3.3.2. Dry density

This was accomplished according to B.S.1881:1952 **[27].** The average density of concrete cube samples containing 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45% and 50% waste glass coarse aggregates was compared with average density of the control concrete [0%WG] cube specimens and the decrease in density was calculated.

3.3.3. Water absorption test

This was accomplished by B.S.1881:1952 **[27].** The average dry weight of all the various cubes specimens after removing from the molds was submerged in water for curing was estimated, the ratio of water absorption was calculated for all concrete mixes.

3.3.4. Compression strength

This was accomplished according to ESS 1658 /2006 **[29].** From each concrete mix, 3 cubes of sizes 15cm X 15cm X 15cm have been cast for the compressive strength determination. Each concrete sample was under curing in normal conditions and each was tested at 28days by using a 2000KN compression machine.

3.3.5. Splitting tensile strength

This was accomplished according to ESS 1658 /2006 **[29].** From each concrete mixture, three cylinders of sizes 150mm diameter X 300mm height have been cast for the splitting tensile strength determination. Each concrete sample was under curing in normal conditions and each was tested at 28days by using a 2000KN compression machine.

IV. Results and Discussion

4.1 Slump test

The slump results of all mixes are denoted in the table [7]. Figure [2] shows that the slump decreased gradually with increasing the content of WG and this is maybe owing to the angular and edged grain shapes of it and this reduction may be also due to the poor geometry of the WG, which results in lesser fluidity of the WG mixes besides the reduction of fineness modulus. Despite the reduction in the slump values, the waste glass concrete mixes were considered workable. The same results were stated by **OlomoRachael.O. et al (2019) [2]** and **Eme D. B. et al (2018) [1].** They verify that the WG concrete slump is lower than that without WG, also reported that with increasing of coarse waste glass aggregate ratio the concrete slump decreased. For 50% WG content, the slump was the minimum.

Table [7] Slump results

WG content %	Slump [cm]
0%	10
5%	9.5
10%	9
15%	8.8
20%	8
25%	7.8
30%	7.2
35%	7
40%	6.8
45%	6.5
50%	6.3

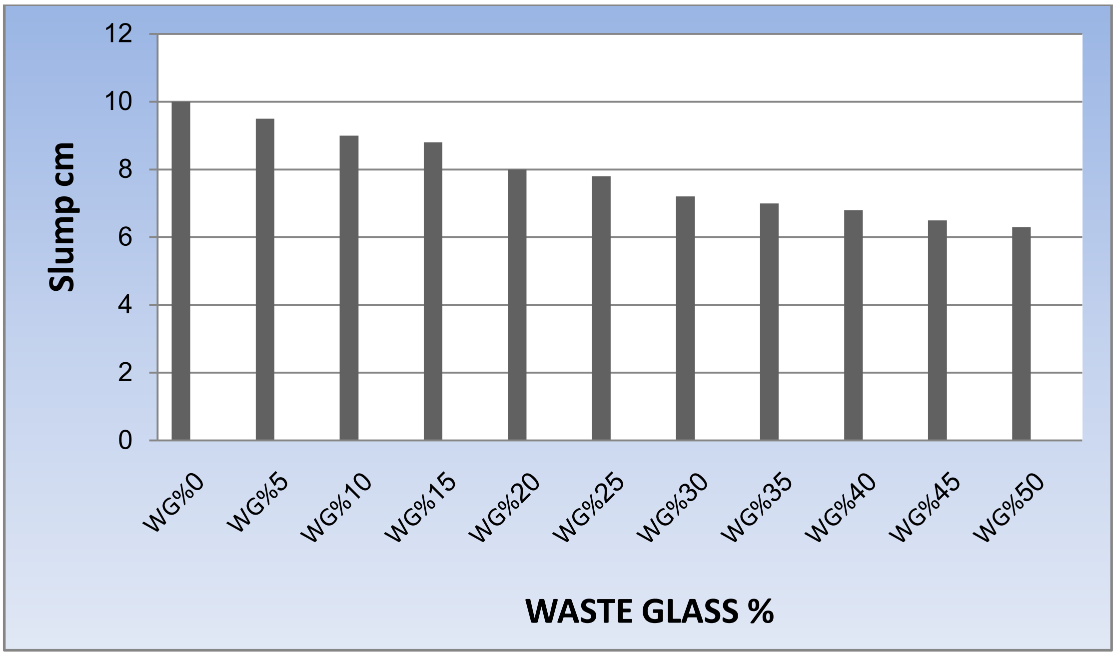

Figure [2] Values of the slump [cm]

4.2 Dry density

Table [8] and Figure [3] give the dry density results and the variation in it concerning the control mix [0%WG]. For each mixture, dry density was calculated. From the computations, it was seen that the density decreased with increasing the WG content. The calculations showed about 14% reduction in concrete dry density of mix with 50% WG replacement as compared to the control mix [0%WG]. The dry density decreasing of the WG concrete can be attributed to the WG unit weight which is lower than that of the basalt.

Table [8] Dry density results

WG content %	Dry density[kg/m^3]	% of dry density reduction
0%	2350	Control
5%	2317	1.4%
10%	2295	2.34%
15%	2255	4.04%
20%	2211	5.91%
25%	2196	6.55%
30%	2161	8.04%
35%	2123	9.66%
40%	2090	11.06%
45%	2056	12.51%
50%	2019	14.08%

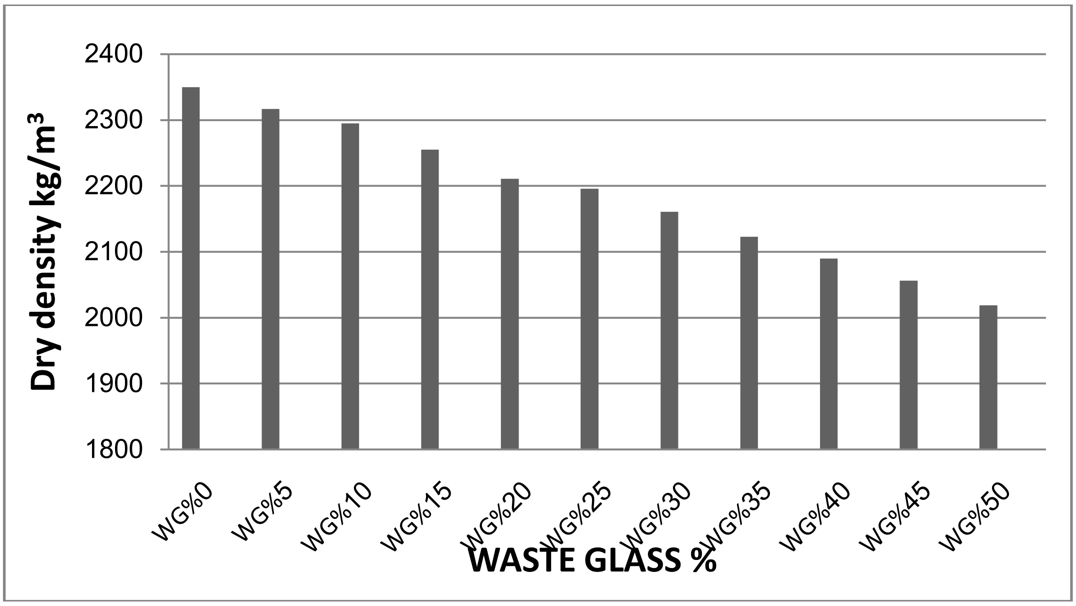

Figure (3): Values of dry density

4.3 Water absorption

Table [9] represents the level of water absorption ratio for all mixes. Figure [4] shows that the percentage of water absorption decreased with the increasing of the WG content, and this is likely because the glass water absorption ratio is almost zero. Same results were stated by **MuzamilLiaqat et al (2018**) **[3]**, they verified that the WG concrete water absorption ratio is lower than that of concrete without WG, they also reported that with the increasing of the WG coarse aggregate ratio the concrete water absorption ratio decreased. In this study, the lowest value of the water absorption ratio was found at 50% WG content.

Table [9] Water absorption results

WG content %	Water absorption %
0%	1.13
5%	1.05
10%	0.95
15%	0.92
20%	0.85
25%	0.82
30%	0.80
35%	0.65
40%	0.60
45%	0.52
50%	0.50

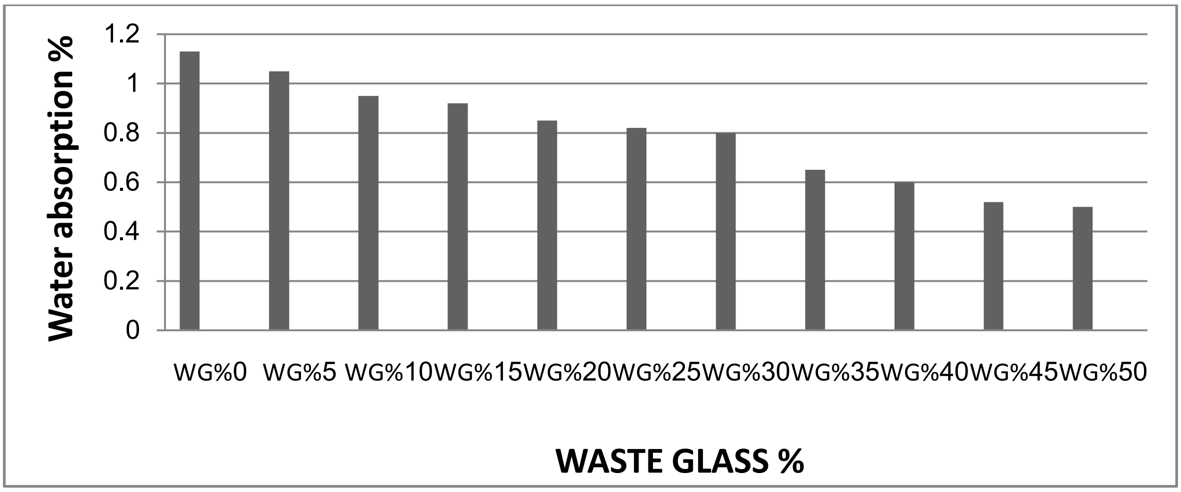

Figure [4] Values of water absorption

4.4Compressive strength

The test results of the compressive strength of the control and recycled glass concrete mixes at 28 days are summarized in Table [10]. Each given value is the average of three measurements. It is evident from Table [10] that the use of recycled glass waste as a basalt replacement until a 25% replacement ratio increases the compressive strength of the concrete mixes compared with the control mixture (0%WG). As shown in Table [10], the increase in 28 days compressive strength of recycled glass concrete mixes was [6.72%, 8.77%, 10.23%, 11.46%, 13.65%] respectively. Also, it can be noticed from Figure [5] that as the WG content increases from 25% to 50%, the compressive strength decreased gradually and the reduction of concrete compressive strength is about 18% at 50% ratio compared with the control mixes. The same results were stated by **OlomoRachael.O. et al (2019) [2]**. They reported that with the increasing of WG coarse aggregate ratio until 25% the concrete compressive strength increased, after this value, the compressive strength of concrete decreased. This is in agreement with the results obtained in this research work.

Table [10] Concrete compressive strength [MPa] at 28 days

WG content %	Compressive strength [MPa]
0%	34.2(control)
5%	36.5(+6.72%)
10%	37.2(+8.77%)
15%	37.7(+10.23%)
20%	38.12(+11.46%)
25%	38.87(+13.65%)
30%	34.06(-0.41%)
35%	32.72(-4.33%)
40%	32.53(-4.88%)
45%	31.12(-9.00%)
50%	28.09(-17.86%)

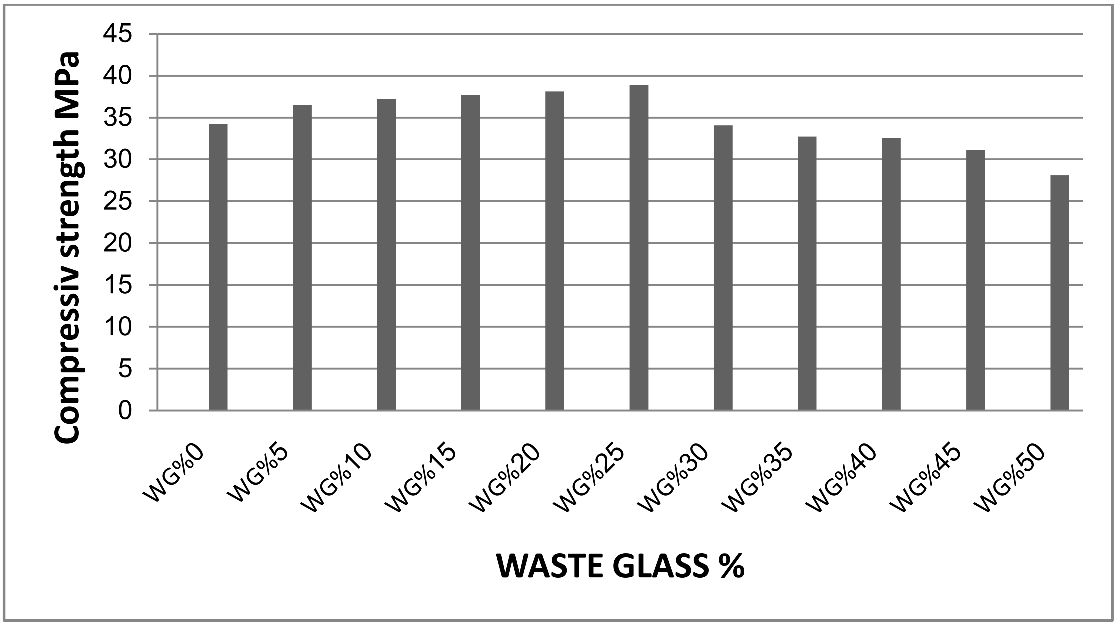

Figure [5] Compressive strength [MPa] of concrete after 28 days

4.5Tensile strength

The obtained splitting tensile strengths after 28 days are presented in Table [11]. Each value is the average of three measurements. Figure [6] shows that the splitting tensile strength tends to increase with the increases in the percentage of recycled waste glass replacement in the concrete mixture until a 25% ratio, compared with the control mixes. According to the test results the 28 days splitting tensile strength values are observed to increase by 9.62%, 10.04%, 11.3%, 12.55%, 14.64%, for replacement ratios of 5%, 10%, 15%, 20%, and 25%, respectively. These outcomes concur with VikashAgrawal. et al (2018) **[30].** They revealed that for 5% reused glass substitution, the splitting tensile strength of recycled glass concrete increased by 4% at 28 days. Likewise, it very well may be seen from Table [11] and Figure [6] that as the WG content increases from 25% to 50%, the splitting tensile strength decreased gradually and the reduction of concrete splitting tensile strength was about 21% at 50% ratio compared with the control mixes.

Table [11] Tensile strength [MPa] of concrete after 28 days

WG content %	Tensile strength [MPa]
0%	2.39(control)
5%	2.62(+9.62%)
10%	2.63(+10.04%)
15%	2.66(+11.3%)
20%	2.69(+12.55%)
25%	2.74(+14.64%)
30%	2.36(-1.25%)
35%	2.29(-4.18%)
40%	2.13(-10.87%)
45%	1.91(-20.08%)
50%	1.88(-21.33%)

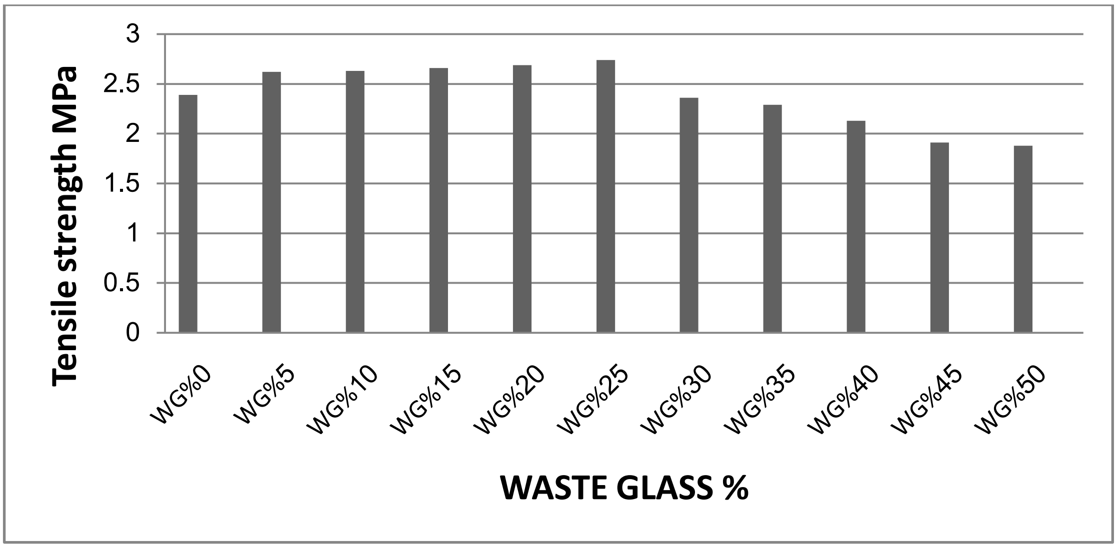

Figure [6] Tensile strength [MPa] of concrete after 28 days

V. Conclusions

1. Basalt can be substituted by coarse WG until 25% proportion without a decrease in compressive and tensile strengths.
2. The 25% waste glass replacement indicated an around 14% increase in compressive strength.
3. The 25% waste glass replacement indicated an around 15 % increase in tensile strength.
4. With increasing the substitution proportion of coarse WG, water absorption decreases.
5. The best dose of coarse waste glass substitution is 25%.
6. The color of concrete does not change during utilizing coarse WG.
7. The density reduced by about 14% when using 50% coarse WG.
8. The workability reduced by increasing the WG quantity.

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