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EXPERIMENTAL STUDY ON MECHANICAL PROPERTIES OF CONCRETE CONTAINING WOLLASTONITE AND GROUND GRANULATED BLAST FURNACE SLAG AS A PARTIAL REPLACEMENT OF CEMENT

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Abstract - *In this era of global warming on vast scale, every possible solution to cut down emission of CO_2 are being developed and one of the major emission take place from the process of making cement. To counter this problem many material like fly ash, GGBS, silica fume, wollastonite, waste glass powder are used as a partial replacement of cement. Partially replacing cement with wollastonite and Ground Granulated Blast Furnace Slag helps in reducing environmental pollution. Wollastonite is naturally occurring mineral and is cheaper than compared to cement. In this project particular we are studying the strength properties of concrete by adding wollastonite and Ground Granulated Blast Furnace slag in it to some desirable percentage with simultaneous replacing the cement percentage by maintaining w/c ratio. This is further help in reducing cement production and thus the greenhouse effect at some extent.*

Key Words*: *Concrete, Wollastonite, GGBS, Partial replacement, Cement, Compressive, Flexural strength.

1. INTRODUCTION

Concrete is a very strong and versatile moldable construction material. It consists of cement, sand and aggregate e.g., gravel or crushed rock mixed with water. Demand for concrete as a construction material is on the increase and so increases the production of cement. The production of cement is increasing about 3% annually. Many countries are observing a fast growth in the construction industry, which involve the use of natural resources for the development of the infrastructure. Thus, we can replace the costly and limited natural resources with the inventive and environmentally friendly alternate building materials. The use of waste product in concrete will not only make it economical but also help in reducing the dumping problems.

To deal with environmental issues we need to find the Alternating sources. And from many general studies we can conclude that addition of minerals admixtures to concrete gives more durable concrete which is more resistance to concrete degradation. Wollastonite is naturally occurring mineral formed due to interaction of limestone with silica in hot magmas. It is chemically calcium metasilicate wollastonite was found to possess reinforcing quality and resistance to chemical attack even in high temperature. There are two main components that form the mineral wollastonite: CaO and Si02. In a pure CaSi03, each part forms almost half of the mineral by weight percentage.It is white mineral highly modulus. It is being used for reduction of shrinkage cracks ceramic tiles and refractory improvement in tensile strength of plastics.

Ground Granulated Blast furnace Slag (GGBS) is a by product from the blast furnaces used to make iron. These operate at a temperature of about 1500 degrees centigrade and are fed with a carefully controlled mixture of iron ore, coke and Limestone. The iron ore is reduced to iron and the remaining materials from a slag that floats on top of the iron. This slag is periodically tapped off as a molten liquid and if it is to be utilized for the manufacture of GGBS it has to be rapidly quenched in large volumes of water. The quenching optimizes the cementitious properties and produces granules similar to coarse sand. This granulated slag is then dried and ground to a fine powder. It can also be referred to as "GGBS" or "Slag cement".

Thus, GGBS acts as pozzolans and is therefore combined with Portland cement; resulting in a hardened cement of GGBS combined with Portland cement, which has more of smaller gel pores and fewer larger capillary pores than that of normal Portland cement which consequently results in lower permeability and hence greater durability. Moreover, it contains less free lime, which in its presence forms ettringite or efflorescence, and makes the resulting hardened cement more chemically stable. This paper presents experimental work carried out to determine the effect of partial replacement of OPC with GGBS and wollastonite. The slump test, Compacting factor test, compressive strength, tensile splitting strength and Durability test for Acid attack are investigated. The optimum wollastonite and GGBS content is also determined.

Table 1.1 Chemical Properties of Wollastonite and GGBS

Binder	Wollastonite(%)	GGBS(%)
SiO_2	50.80	32.84
C_aO	40.88	40.80
Fe_2O_3	0.11	0.28
TiO_2	0.04	0.47
Al_2O_3	0.27	13.27
MgO	3.05	6.08
LOI	4.85	5.55

2. BACKGROUND LITERATURE

According to previous study of Aditya Rana, Pawan Kalla and Sarabjeet Singh With addition of wollastonite in concrete mixes compressive strength dropped marginally at water binder 0.45 and 0.50 but noticeable strength was witnessed at 0.45 water binder ratio[1]. According to M. BorkarS.Zade, B.Dongre, and P.Sakharkar the strength properties of concrete by addition wollastonite in it to a few desirable percentages with simultaneously replacing the cement percentage by maintaining w/c ratio. This would further help in reducing cement production and thus the green house effect at some level. In this view they will study the amount of cement which can be replaced without disturbing the strength of concrete[2].

According to Reshma Rughooputh and Jaylina Ranathe compressive and split tensile strength, flexure and modulus of elastic increased as the GGBS content increased. The percentage drying shrinkage showed a minor increment with the partial replacement of OPC with GGBS. However, concrete containing GGBS unsuccessful the initial surface absorption test confirm that GGBS decreases the permeability of concrete. The optimum mix was found the one with 50% GGBS replacement [3]. According to B.Mangamma, Dr N.Victor babu, G.Hymavathi when use the GGBS in partial replacement of cement it increase the strength of the cubes as well as reduce the pollution of the environmental. In this study GGBS used at 10%, 20%, 30%, 40%, 50% for M20 and M30 grades. It is gives increase strength values at 10%, 20% and 30% compare to usual mixes [4].

According to Shubham Dahiphale, Kabir Khan, Kshitij Tikhe It was observed that there was a rise in compressive strength at 10%, 12.5%, and 15% wollastonite replacement as compared to control mix. Highest rise was observed at 15% wollastonite replacement. Result of wollastonite on properties of concrete like compressive strength was investigated at 3 days, 7 days and 28 days. With the increase in wollastonite content, workability was establish to be decrease a little as compared to control mix[5]. According to Srushti zade, Meeyosh borkar, Payal makode it was observed that there was an increase in compressive strength at 10%, 15% wollastonite replacement as compared to control mix. Compressive and flexural strength of concrete mixes were evaluated. The major factor affecting the durability of concrete is permeability, occurrence of micro-cracks in the concrete due to heat of hydration of cement and correlated stresses, carbonation, chloride ingress and corrosion. These can be controlled by restricting the movement of moisture in the concrete [6].

According to Dr. G. Sridevi, L. Madhusudhan, V. Manikumar Reddy GGBS concrete has better water impermeability characteristics as well as better resistance to corrosion and sulphate attack. As a result, the overhaul life of a structure is improved and the maintenance cost reduced. High volume eco friendly substitute slag leads to the development of concrete which not only utilize the industrial wastes but also saves significant importance[7].According to M. Rajaram, A. Ravichandran test results prove that the compressive strength, split tensile strength and flexural strength of concrete mixture increases as the quantity of GGBS increase[8].

3. Material

3.1 Cement

The cement used in this project is an ordinary Portland cement 53 grade manufacturing by Hathi Cement Company. The Specific gravity and fineness modulus of cement is 3.15 and 6% respectively.

3.2 Fine Aggregate

River sand passing through 4.75 mm IS sieve conforming to grading zone II of IS 383:1970 and having a specific gravity of 2.64 was used in this work.

3.3 Coarse Aggregate

Crushed aggregate available from local sources with a size of 10mm and 20 mm having a specific gravity is respectively 2.99 and 2.88 and also conforming to IS 2386:1963 was used as coarse aggregate in this study.

3.4 GGBS

Ground Granulated Blast-furnace Slag is a cementitious material whose major use is in concrete and is a by product from the blast-furnaces use to make iron GGBS having a specific gravity of 2.80 was used in this study to determine the optimum replacement level.

3.5 Wollastonite

Wollastonite is a calcium inosilicate mineral ($CaSiO_3$) that may include little amounts of iron, magnesium and manganese substituting for calcium. Specific Gravity of Wollastonite is a range between 2.87 to 3.09.

4. Experimental Study

4.1 Mixing and Curing

After the mix design of the M20, M30, M40 grade concrete mix proportions were arriving and tabulated in table 4.1. Initially the dry materials, Cement, Aggregates & Sand are mixed. Further, GGBS and Wollastonite were added into the dry mixture for another 1 minute. The fluid part of the mixture was then added to the dry materials and the mixing continued for further about 4 minutes. The total mixing time was 5 minutes. Compaction of concrete in three layers with 25 strokes of 16mm rod was carried out for each layer is done. The concrete was left in the mold and allowed to set for 24 hrs before the cubes were de-molded and placed in the curing tank until the day of testing.

Table 4.1: Mix Proportion for 1m^3

Concrete Grade	Water (Kg/m^3)	Cement (Kg/m^3)	Fine Agg. (Kg/m^3)	Coarse Agg. (Kg/m^3)
M20	197.16	397.15	796.97	1118.56
M30	197.16	448.09	771.31	1082.53
M40	197.16	492.9	754.97	1039.75

4.2 Testing of Specimens

The mixtures of concrete containing combination of wollastonite added as a partial cement replacement of 0%, 7.5%, 10% and 20% with GGBS combination with 0%, 10%, 20%, 30%, 40% by weight and the specimens were tested. 150 x150x150mm concrete cubes manufactured from each mixture were tested for compressive strength after storage in water for a period 28days. The testing is carried out for compressive strength on the cubes as per IS: 516 – 1959. Compressive strength of cubes is determined by using compression testing machine (CTM) of 2000 KN. The testing is carried out for split tensile strength on cylinder as per IS: 5816 – 1999. Cylinders of 150mm diameter and 300mm length were used as test specimens to determine the split tensile strength of concrete for both cases (normal concrete and GGBS concrete). The cylindrical specimen was placed horizontally between the loading surfaces of the compression testing machine and the load was applied to the failure of the specimen. The concrete beams of size (100mm x 100mm x 500mm) were tested as per IS: 516 – 1959 for flexural strength.

5. Test Result and Discussion

5.1 Slump Test

Slump values with various proportions of wollastonite and GGBS replacing cement in M20, M30, and M40 grade concrete were shown in the table 5.1.

Table 5.1: Slump values with various proportions of GGBS and Wollastonite

Mix Type	Wollastonite (%)	GGBS (%)	M20 (mm)	M30 (mm)	M40 (mm)
M1	0	0	55	56	58
M2	0	10	57	58	59
M3	0	20	59	60	62
M4	0	30	60	60	64
M5	0	40	61	62	66
M6	7.5	0	56	58	59
M7	7.5	10	58	61	63
M8	7.5	20	61	62	65
M9	7.5	30	63	65	67
M10	7.5	40	64	65	70
M11	15	0	57	58	61
M12	15	10	59	62	64
M13	15	20	62	65	67
M14	15	30	64	66	69
M15	15	40	66	67	71
M16	20	0	58	60	63
M17	20	10	62	65	67
M18	20	20	65	68	70
M19	20	30	67	72	73
M20	20	40	69	72	74

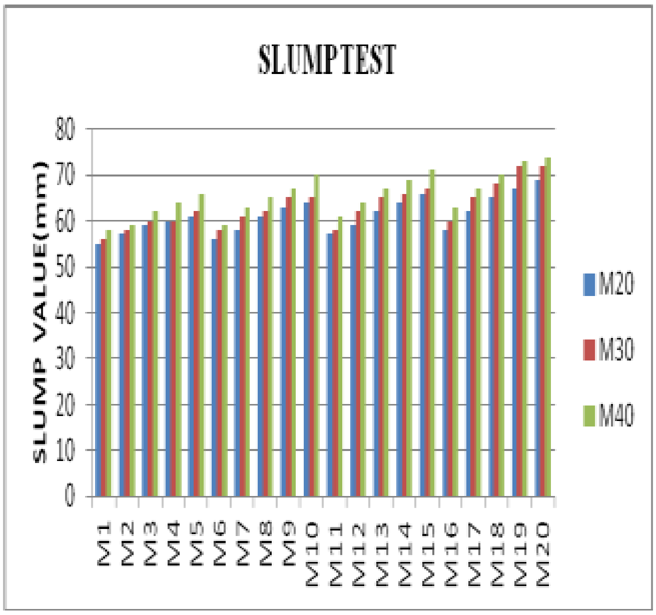


Figure 5.1: Workability of Concrete with varying % Wollastonite and GGBS content

5.2 Compacting Factor Test

Compaction values with various proportions of wollastonite and GGBS replacing cement in M20, M30, and M40 grade concrete were shown in the table 5.2.

Table 5.2: Compaction Factor values with various proportion of wollastonite and GGBS

Mix Type	Wollastonite (%)	GGBS (%)	M20	M30	M40
M1	0	0	0.80	0.81	0.82
M2	0	10	0.82	0.82	0.82
M3	0	20	0.82	0.83	0.84
M4	0	30	0.83	0.85	0.85
M5	0	40	0.84	0.86	0.87
M6	7.5	0	0.81	0.81	0.82
M7	7.5	10	0.82	0.82	0.83
M8	7.5	20	0.83	0.84	0.85
M9	7.5	30	0.83	0.85	0.86
M10	7.5	40	0.84	0.86	0.86
M11	15	0	0.82	0.83	0.84
M12	15	10	0.84	0.84	0.84
M13	15	20	0.84	0.85	0.86
M14	15	30	0.85	0.86	0.87
M15	15	40	0.85	0.86	0.88
M16	20	0	0.83	0.84	0.84
M17	20	10	0.83	0.85	0.86
M18	20	20	0.84	0.85	0.87
M19	20	30	0.85	0.87	0.88
M20	20	40	0.86	0.87	0.89

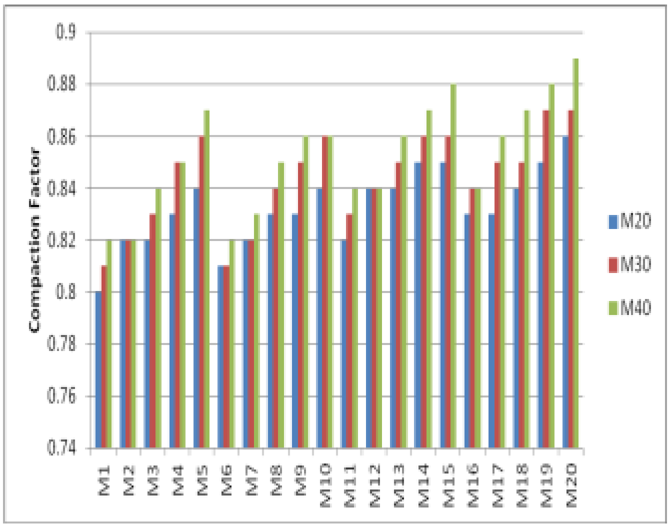


Figure 5.2: Compaction factor of Concrete with varying % Wollastonite and GGBS content

5.3 Compressive Strength Test

A cube specimen was cast to find out the compressive strength of the concrete. Compressive strength of concrete mixtures made with wollastonite and GGBS was determined 28 days of curing. The average of three samples was taken for every testing age. The test results for compressive strength are presented in table 5.3.

Table 5.3: Compressive Strength for M20, M30, M40 grade Concrete

Mix Type	Wollastonite (%)	GGBS (%)	M20 MPa	M30 MPa	M40 MPa
M1	0	0	27.85	39.9	49.25
M2	0	10	29.59	42.58	51.28
M3	0	20	31.96	43.66	53.23
M4	0	30	33.68	45.84	56.88
M5	0	40	29.63	42.62	52.32
M6	7.5	0	30.75	42.50	51.85
M7	7.5	10	33.75	43.74	53.47
M8	7.5	20	34.55	44.70	54.59
M9	7.5	30	32.72	42.88	52.96
M10	7.5	40	28.23	40.22	49.82
M11	15	0	31.50	43.24	52.48
M12	15	10	34.74	44.72	53.72
M13	15	20	35.70	45.87	55.14
M14	15	30	32.70	42.88	51.52
M15	15	40	30.82	40.14	49.45
M16	20	0	28.72	38.22	48.68
M17	20	10	29.55	39.11	49.22
M18	20	20	30.35	40.1	50.85
M19	20	30	29.11	39.55	49.70
M20	20	40	27.22	37.33	47.86

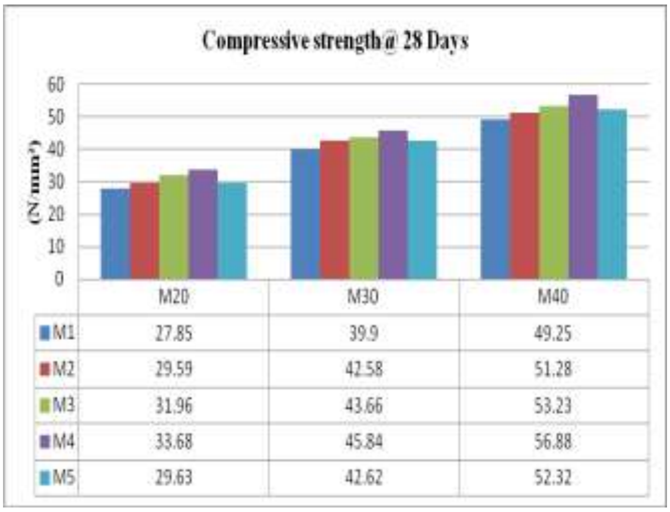


Figure 5.3: Compressive Strength of Cube

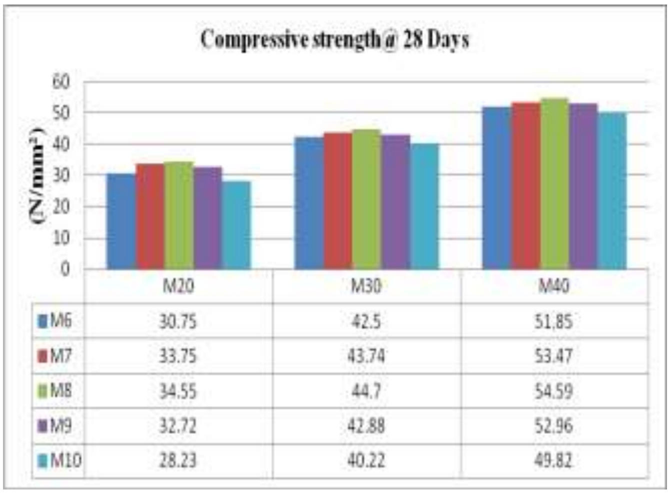


Figure 5.4: Compressive Strength of Cube

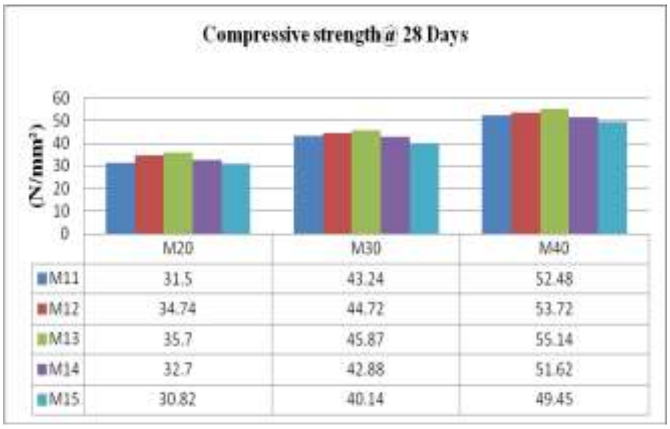


Figure 5.5: Compressive Strength of Cube

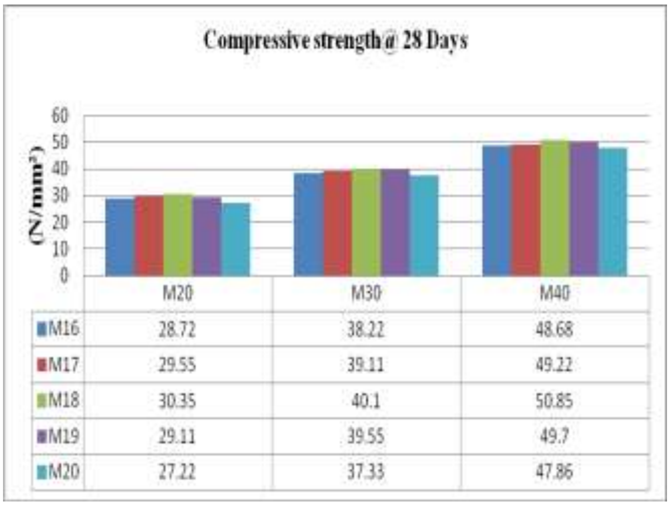


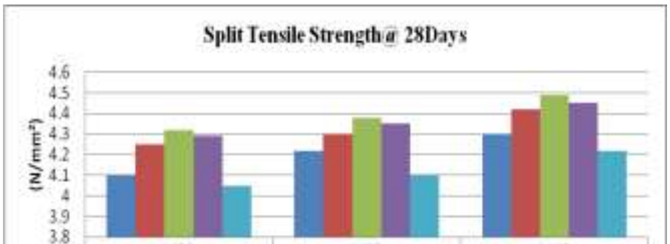
Figure 5.6: Compressive Strength of Cube

5.4 Split Tensile Strength Test

A cylindrical specimen was cast to find out the split tensile strength of the concrete and the average of three cylinders for each mix was tested. Split tensile strength of concrete specimens made with wollastonite and GGBS was determined at 28 days of curing.

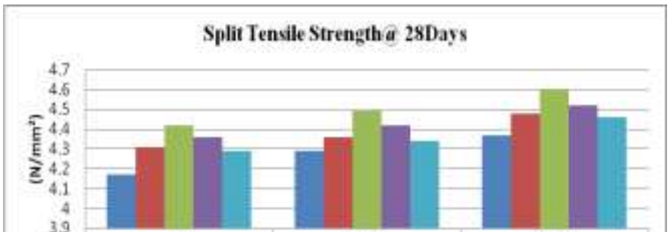
Table 5.4: Split Tensile Strength for M20, M30, and M40 grade Concrete

Mix Type	Wollastonite (%)	GGBS (%)	M20 MPa	M30 MPa	M40 MPa
M1	0	0	4.10	4.22	4.30
M2	0	10	4.25	4.30	4.42
M3	0	20	4.32	4.38	4.49
M4	0	30	4.29	4.35	4.45
M5	0	40	4.05	4.10	4.22
M6	7.5	0	4.17	4.29	4.37
M7	7.5	10	4.31	4.36	4.48
M8	7.5	20	4.42	4.49	4.60
M9	7.5	30	4.36	4.42	4.52
M10	7.5	40	4.29	4.34	4.46
M11	15	0	4.26	4.38	4.46
M12	15	10	4.40	4.45	4.57
M13	15	20	4.44	4.51	4.62
M14	15	30	4.34	4.40	4.54
M15	15	40	4.30	4.35	4.47
M16	20	0	4.35	4.47	4.55
M17	20	10	4.45	4.60	4.72
M18	20	20	4.58	4.65	4.76
M19	20	30	4.65	4.71	4.82
M20	20	40	4.45	4.5	4.82



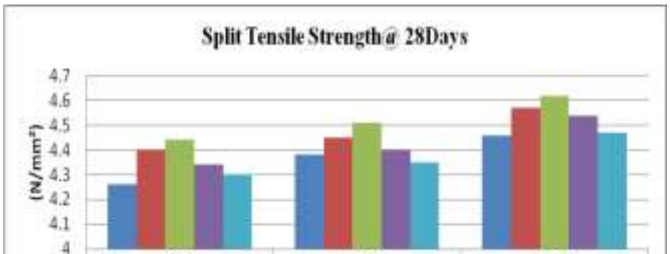
	M20	M30	M40
M1	4.1	4.22	4.3
M2	4.25	4.3	4.42
M3	4.32	4.38	4.49
M4	4.29	4.35	4.45
M5	4.05	4.1	4.22

Figure 5.7: Split Tensile Strength of Cylinder



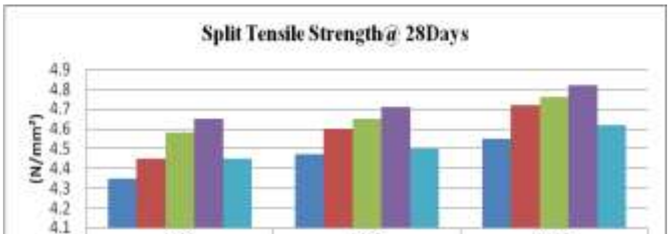
	M20	M30	M40
M6	4.17	4.29	4.37
M7	4.31	4.36	4.48
M8	4.42	4.49	4.6
M9	4.36	4.42	4.52
M10	4.29	4.34	4.46

Figure 5.8: Split Tensile Strength of Cylinder



	M20	M30	M40
M11	4.26	4.38	4.46
M12	4.4	4.45	4.57
M13	4.44	4.51	4.62
M14	4.34	4.4	4.54
M15	4.3	4.35	4.47

Figure 5.9: Split Tensile Strength of Cylinder



	M20	M30	M40
M16	4.35	4.47	4.55
M17	4.45	4.6	4.72
M18	4.58	4.65	4.76
M19	4.65	4.71	4.82
M20	4.45	4.5	4.62

Figure 5.10: Split Tensile Strength of Cylinder

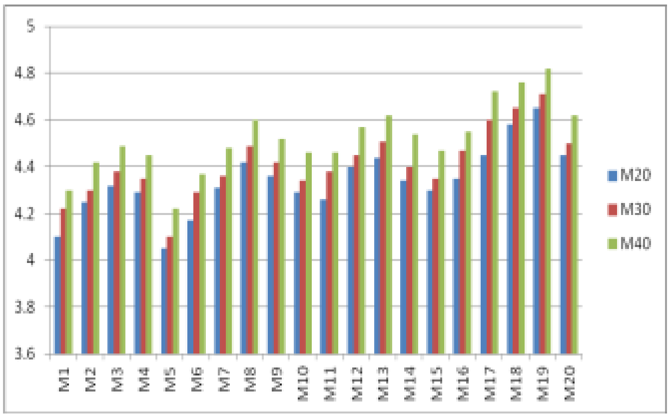
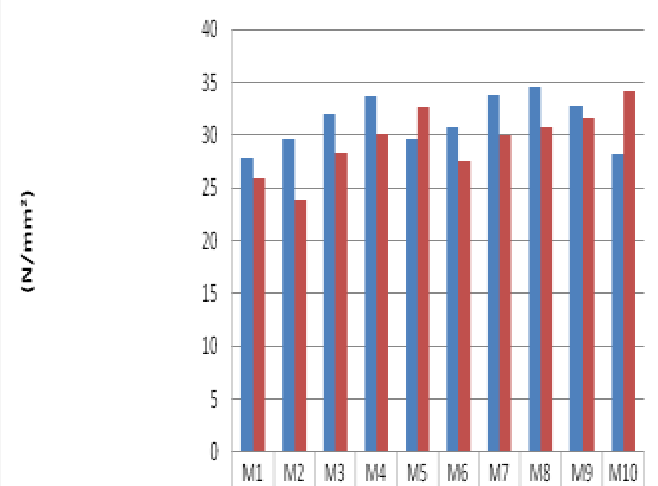


Figure 5.11: Split Tensile Strength of Cylinder

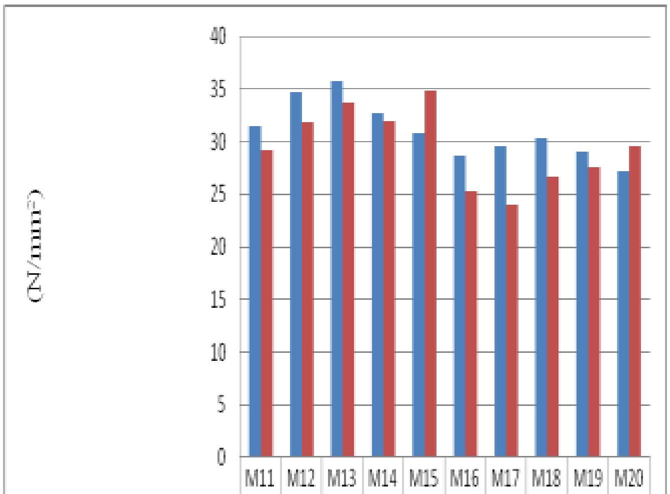
5.5 Durability Test

The concrete cubes of size 150mm were cast and cured for a period of 28 days. After 28 days curing of specimens, cube surfaces were cleaned and weighed. The specimens were immersed in HCL acid solution. The solution was checked periodically. After the 28 days, the specimens were removed from the solution. Percentage weight loss was determined and percentage of strength loss determined. To conduct this test, 3% by volume of hydrochloric acid was mixed with ordinary potable water.



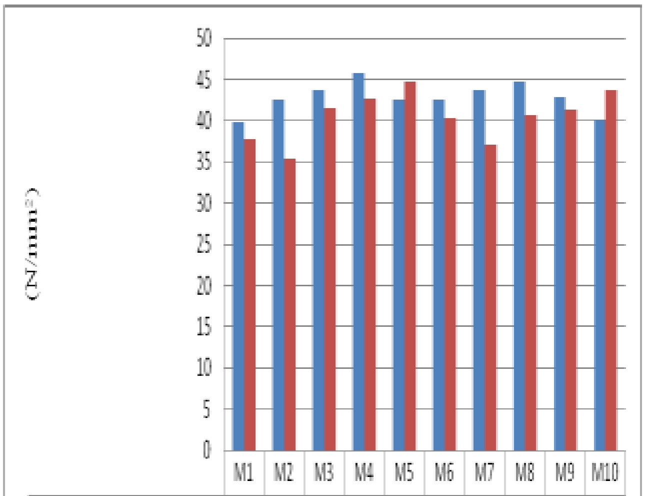
	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
NORMAL COMPRESSIVE STRENGTH	27.85	29.59	31.96	33.68	29.63	30.75	33.75	34.55	32.72	28.23
COMPRESSIVE STRENGTH DUE TO HCL	25.85	23.82	28.33	30.14	32.62	27.58	29.95	30.69	31.58	34.15

Figure 5.12: Compressive strength of **M20** grade cubes after performing durability test in acid attack



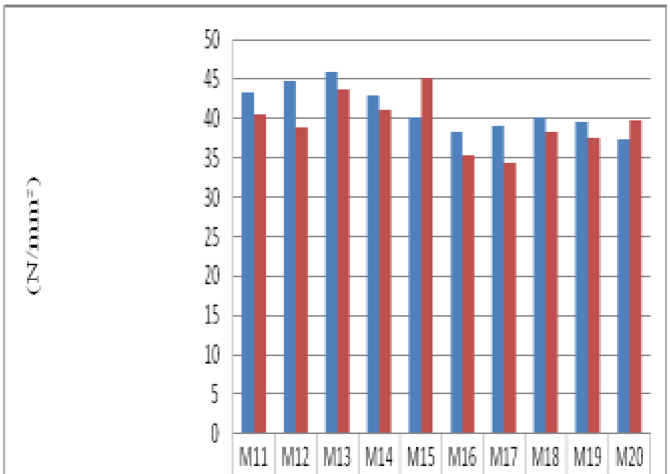
	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20
NORMAL COMPRESSIVE STRENGTH	31.5	34.74	35.7	32.7	30.82	28.72	29.55	30.35	29.11	27.22
COMPRESSIVE STRENGTH DUE TO HCL	29.25	31.84	33.69	31.95	34.85	25.27	23.98	26.69	27.58	29.53

Figure 5.13: Compressive strength of **M20** grade cubes after performing durability test in acid attack



	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
NORMAL COMPRESSIVE STRENGTH	39.9	42.58	43.66	45.84	42.62	42.5	43.74	44.7	42.88	40.22
COMPRESSIVE STRENGTH DUE TO HCL	37.75	35.35	41.55	42.72	44.68	40.28	37.11	40.68	41.33	43.72

Figure 5.14: Compressive strength of **M30** grade cubes after performing durability test in acid attack



	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20
NORMAL COMPRESSIVE STRENGTH	43.24	44.72	45.87	42.88	40.14	38.22	39.11	40.1	39.55	37.33
COMPRESSIVE STRENGTH DUE TO HCL	40.58	38.9	43.63	41.14	45.27	35.28	34.33	38.27	37.63	39.75

Figure 5.15: Compressive strength of **M30** grade cubes after performing durability test in acid attack

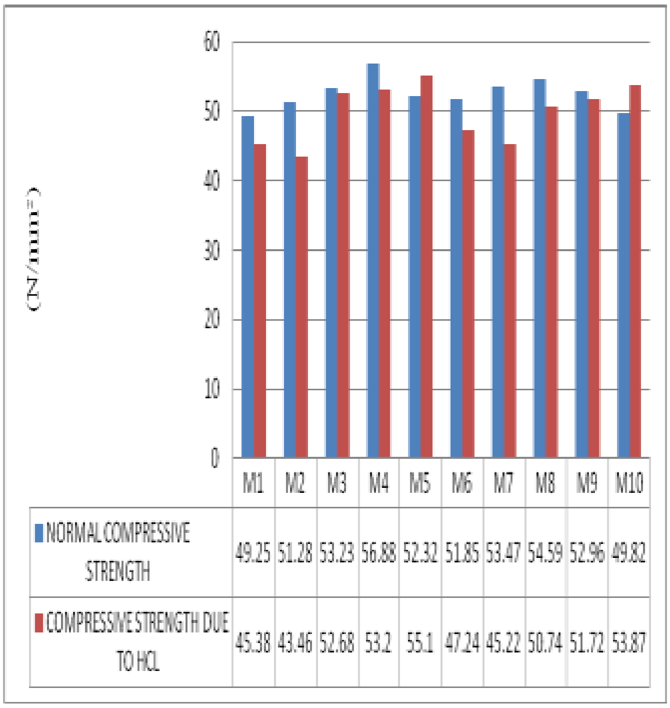


Figure 5.16: Compressive strength of **M40** grade cubes after performing durability test in acid attack

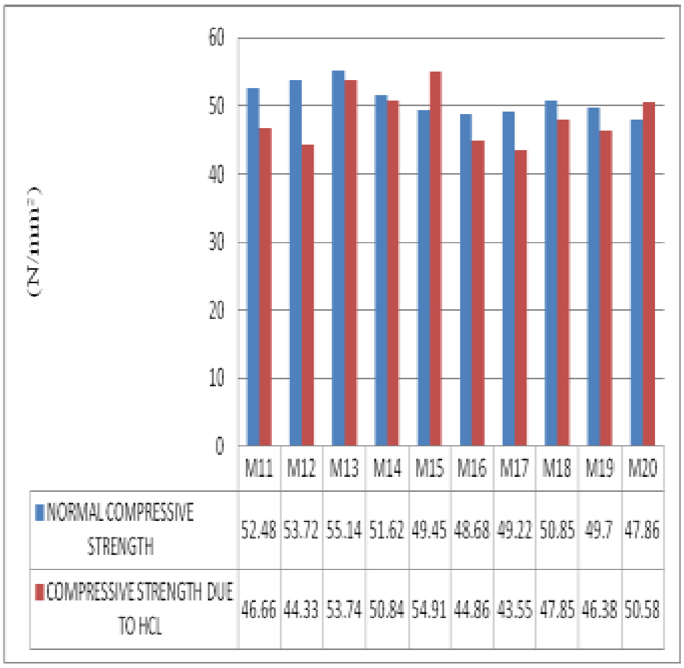


Figure 5.17: Compressive strength of **M40** grade cubes after performing durability test in acid attack

CONCLUSIONS

- The workability of the concrete increases with the increase in the GGBS content for M20, M30, M40 grade concrete and the workability reaches its maximum at 40% replacement of GGBS.
- The slump value and compacting factor value of concrete will be increases with the increase in the GGBS content for M20, M30, M40 grade concrete and the workability reaches its maximum at 40% replacement of GGBS.
- Tensile Strength of M20, M30, and M40 grade concrete goes on increasing up to 20% replacement of cement by GGBS.
- For 20% GGBS and 0%, 7.5%, 15%, 20% wollastonite replaced with cement gives optimum dosage which gives higher Tensile strength of concrete as compare to concrete mix in which cement was only replaced by 20% GGBS.
- To obtain maximum compressive strength of concrete at the 15% replacement of wollastonite with cement.
- Compressive strength of M20, M30, and M40 grade concrete produced by replacing cement by GGBS goes on increasing up to 30% replacement of cement by ggbs and reaches peak at 20%.
- For 20% GGBS and 7.5% wollastonite replaced with cement gives optimum dosage which gives higher compressive strength of concrete as compare to concrete mix in which cement was only replaced by 20% GGBS.
- For 20% GGBS and 15% wollastonite replaced with cement gives optimum dosage which gives higher compressive strength of concrete as compare to concrete mix in which cement was only replaced by 20% GGBS.
- For 20% GGBS and 20% wollastonite replaced with cement gives optimum dosage which gives higher compressive strength of concrete as compare to concrete mix in which cement was only replaced by 20% GGBS.
- Durability of Concrete will be increases with increase the percentage of GGBS replacement with cement.
- The durability of the concrete increases with the increase in the GGBS content for M20, M30, M40 grade concrete and the workability reaches its maximum at 40% replacement of GGBS.

REFERENCES

[1]. Kalla, P., Rana, A., Chad, Y.B., Misra, A. and Csetenyi, L., 2015. Durability studies on concrete containing wollastonite. *Journal of Cleaner Production*, *87*, pp.726-734.

[2]. Zade, S.D., borkar, M., motghare, R.D., Makode, P.D., Sakharkar, P.R., badhekar, P., & Dongre, B. (2019). To

study the strength of concrete by adding wollastonite in it. *International Journal of Advance Research and Innovative Ideas in Education, 5*, 693-699.

[3]. Rughooputh, R. and Rana, J., 2014. Partial replacement of cement by ground granulated blast furnace slag in concrete. *Journal of Emerging Trends in Engineering and Applied Sciences*, *5*(5), pp.340-343.

[4]. Mangamma, Dr N.Victor babu, G.Hymavathi, An Experimental Study on Behavior of Partial Replacement of Cement with Ground Granulated Blast Furnace Slag. *International Journal of Engineering Research and Application.vil, 6.*

[5]. Shubham Dahiphale, Kabir Khan, Kshitij Tikhe., 2018. Properties of Concrete Containing Wollastonite. *International Journal of Engineering Research in Mechanical and Civil Engineering*. *vol,5*, pp.2018.

[6]. Zade, S. D., Meeyosh borkar, Payal Devidas Makode, P. R. Sakharkar, To study the strength of concrete by adding wollastonite in it. *International Journal of Advance Research and Innovative Ideas in Education* 5 (2019): 693-699.

[7]. Dr. G. Sridevi, L. Madhusudhan, V. Manikumar Reddy,2016. Studies on Strength Properties of Concrete with Partial Replacement of Cement by GGBS. *International Journal of Scientific & Engineering Research. Vol,7.*

[8]. Rajaram, M., Ravichandran, A. and Muthadhi, A., 2017. Studies on optimum usage of GGBS in concrete. *Int J Innov Sci Res Technol*, *2*(5), pp.773-778.

[9]. Sathish, P. and Murugesh, V., 2016. Experimental Study on Sisal Fibre Reinforced concrete With Partial Replacement of Cement by Ground Granulated Blast furnace Slag. *vol*, *5*, pp.2013-2016.

[10]. Kalla, P., Misra, A., Gupta, R.C., Csetenyi, L., Gahlot, V. and Arora, A., 2013. Mechanical and durability studies on concrete-containing wollastonite and fly ash combination. *Construction and Building Materials*, *40*, pp.1142-1150.

[11]. Arivalagan, S., 2014. Sustainable studies on concrete with GGBS as a replacement material in cement. *Jordan journal of civil Engineering*, *159*(3147), pp.1-8.

[12]. Rajaram, M., Ravichandran, A. and Muthadhi, A., 2017.Studies on optimum usage of GGBS in concrete. *Int J Innov Sci Res Technol*, *2*(5), pp.773-778.

[13]. Babu, K.G. and Kumar, V.S.R., 2000. Efficiency of GGBS in concrete. *Cement and Concrete Research*, *30*(7), pp.1031-1036.

[14]. IS 383-1970 (Reaffirmed 1997),Indian Standard code of practice-specification for coarse and fine aggregates from natural sources for concrete, Sieve Analysis, Bureau of Indian Standards, New Delhi, India.

[15]. IS 2386:1963 Part III for Specific Gravity, Water Absorption & Bulk Density of Aggregate.

[16]. IS 2386:1963 Part IV for Aggregate Impact Value & Aggregate Crushing Value.

[17]. IS: 2386 Part I - 1963 (Reaffirmed 1997), Indian Standard code of practice- methods of test for aggregates for concrete, Flakiness Index & Elongation Index, Bureau of Indian Standards, New Delhi, India..

[18]. IS 10262: (1982&2009) for Recommended Guidelines for Concrete Mix Designs, Bureau of Indian Standards, New Delhi, India.

[19]. M. S. Shetty, “Concrete Technology”, S. Chand and Company Limited, New Delhi, Sixth Edition, May 2005.