Effect of Alccofine on the Mechanical and Durability Performance of Concrete

ABSTRACT

This paper presents the study on the mechanical and durability properties of concrete at two different grades containing alccofine at different percentages of replacement. Investigation on the performance of alccofine concrete was performed for M25 and M40 grade at 0%, 5%, 10% and 15% replacement levels at 7, 14, 28 and 90 days. The influence of alccofine on the autogenous shrinkage properties of the alccofine added concrete was tested for both the grades of concrete in the sealed and unsealed conditions. The workability property of alccofine added concrete was examined at various levels of replacement by the slump cone test. The mechanical properties of the alccofine added concrete were investigated through estimation of compressive strength and elastic modulus at 7, 14, 28 and 90 days respectively. Acid attack was conducted at 28 days and autogenous shrinkage of the alccofine added concrete was investigated using length comparator at 28 day in the sealed and unsealed conditions. Results indicate that upon increase in the percentage of alccofine, the mechanical properties of the concrete increases at higher ages. Furthermore, the autogenous shrinkage of concrete tends to increase upon increase in the percentage of the alccofine at both the grades of concrete.

Keywords – Alccofine, Mechanical properties, Autogenous shrinkage, Sealed and Unsealed, Workability, Acid attack.

1. INTRODUCTION

Urbanization and industrialization have increased the rate of construction activities in developing countries in recent times. In such a situation, the production and utilization of cement for construction has increased rapidly. Excessive utilization of cement in concrete may increase the strength of the concrete but conversely it increases the rate of shrinkage of concrete [1]. Furthermore, poor compaction results in pore formation that affects the mechanical and durability properties of concrete. This necessitated the utilization of micro filler such as alccofine as supplementary cementitious material that fills up the voids in concrete thereby improving the performance of the concrete. Various researches on the utilization of alccofine have shown better results on the performance of the concrete. With a constant grade of concrete, the improvement in the compressive strength of the concrete was observed upon the addition of alccofine until 10% and beyond which the compressive strength decreases [2]. Conversely, with variation in the w/c ratio from 0.26 to 0.42 and percentages of alccofine from 5% to 25% the compressive strength of the concrete increases which shows an optimal dosage of 15% of alccofine. The maximum compressive strength was reported at 0.42w/c at 28 days as 61.75 N/mm^2 at 15% of alccofine [3]. But the maximum dosage of 25% of alccofine was achieved at 0.42w/c ratio which reports higher compressive strength compared to conventional concrete. The higher water absorption capacity of alccofine concrete is attributed to its higher surface area. [4] Performed the study on the replacement of cement with 5%, 9%, 12% and 15% of alccofine for a M35 grade concrete. The maximum compressive strength was observed as 46.14 MPa at 12% replacement of alccofine at 28 days. Increase in the strength of concrete with alccofine can be observed at the age of 3 days itself due to its higher rate of pozzolanic activity (ACI 226, 1987). Such increase in the strength of the concrete upon addition of alccofine can also be further related to its

workability properties. Increase in the workability of the concrete up to 6% can be observed upon replacement till 10% [5], whereas conversely a decreasing trend in the workability was observed at 7.5% replacement of alccofine [6]. Such decrease in the workability of concrete upon lower levels of replacement of alccofine is due to its higher surface area. In case of high strength concrete, the maximum slump of 180mm was achieved at 5% replacement of alccofine beyond which it causes the reduction in slump at constant w/c ratio and dosage of super plasticizers [7]. With respect to the durability properties, addition of micro filler such as alccofine tends to reduce the permeability on concrete [8, 9, 10]. Shrinkage at the initial ages of concrete due to volume changes should be controlled as it weakens the Interfacial Transition Zone (ITZ) leading to cracking [11, 12]. The above summary clearly demonstrates the lack of study on the shrinkage properties of alccofine concrete in sealed and unsealed conditions. Alccofine is a new generation materials and used as cement replacement instead of alccofine without compromising strength and durability performance of concrete.

This paper presents an experimental investigation on the mechanical properties of alccofine added concrete at 7, 14, 28 and 90 days. This study also encompasses on the autogenous shrinkage properties of alccofine added concrete in sealed and unsealed conditions and resistance of the alccofine added concrete against the ingression of acids at 28 days.

2. MATERIALS AND MIX PROPORTIONS

Ordinary Portland cement of 43 grade confirming to IS: 8112-1989, fine aggregate passing through 2.36mm, coarse aggregate passing through 20mm, alccofine collected from a local market and water confirming to IS 456:2000 were used as raw materials in the study. Chemical constituents of cementitious materials ordinary portland cement and alccofine are

given in table 1. Various physical properties of the raw materials used in the study are presented in the table 2. Mix proportions for M25 and M40 grade of concrete used in the study are presented in the table 3. Control specimens for both grades of concrete were prepared using ordinary portland cement whereas other mixtures were prepared by replacing cement by 5, 10, and 15% of cement by alccofine.

Table 1. Chemical constituents of cementitious materials

No	**Constituents**	**% of the constituents**	
		Ordinary Portland Cement	**Alccofine**
1	SiO_2	17.34	87.41
2	Al_2O_3	7.62	0.8
3	Fe_2O_3	4.23	0.76
4	CaO	61.43	1.41
5	MgO	2.4	1.23
6	SO_3	1.24	0.84

Table 2. Physical properties of raw materials

No	**Raw material**	**Property**	**Obtained Value**	**BIS limits**
1	Cement	Specific Gravity	3.15	3.15
		Setting time	Initial – 30mins Final – 600mins	Initial – 30mins Final – 600mins
2	Fine Aggregate	Specific Gravity	2.74	2.50 to 3.00
		Fineness modulus	2.79	2.00 to 4.00
		Water absorption	1.34%	0.30 to 2.50%
3	Coarse Aggregate	Specific Gravity	2.65	2.50 to 3.00
		Fineness modulus	7.13	6.75 to 8.00
		Water absorption	1.1%	<2.0%
4	Alccofine	Specific Gravity	2.9	-
		Surface area	1200 m^2/kg	> 350 m^2/kg
5	Water	pH	7.5	>6.00

Table 3. Mix proportions of concrete

No	Raw materials (Kg/m^3)	Grade of concrete							
		Percentage of alccofine (M25 grade concrete)				Percentage of alccofine (M40 grade concrete)			
		0%	5%	10%	15%	0%	5%	10%	15%
1	Cement	336	319.2	302.4	285.6	463.5	463.5	463.5	463.5
2	Fine Aggregate	834	834	834	834	530.27	530.27	530.27	530.27
3	Coarse Aggregate	1114	1114	1114	1114	1153.13	1153.13	1153.13	1153.13
4	Water	186	186	186	186	185.4	185.4	185.4	185.4
5	Alccofine	-	16.80	33.60	50.4	-	23.18	46.36	69.54

3. PREPARATION AND TESTING OF SPECIMENS

Concrete cube moulds of size 150mmx150mmx150mm, cylindrical moulds of size 150mmx300mm and prism moulds of size 500mmx100mmx100mm were used for this study. The concrete mixes were prepared in accordance with IS 10262 and raw materials used in the manufacture of concrete were poured in the mixer and allowed to run for 3 minutes to ensure proper mixing of all the ingredients of concrete. Further, the prepared concrete mixes were poured in the prepared moulds and compacted using 25 blows in three layers and allowed to harden for 24 hours. The hardened specimens were tested for mechanical properties in accordance with BS 1881: Part 116: 1983 at 7, 14, 28 and 90 days. Demoulded cube specimens were immersed in acidic solution containing 5% of 0.1M HCl for 28 days and the resistance of the concrete was studied by measuring the decrease in the compressive strength. Demoulded beam specimens were subjected to shrinkage study regularly till 28 days and the volume change was measured using length comparator. Fewer specimens were sealed and kept in controlled condition of $20^{\circ}C$ for the entire 28 days [13].

(a)

(b)

(c)

Fig.1. Casting of concrete specimens

(a)

(b)

(c)

Fig.2. Testing of concrete specimens

4. RESULTS AND DISCUSSIONS

4.1.Fresh property study

Slump value of concrete for M40 grade concrete performed in accordance with BS 1881: Part 102: 1983 with different percentage of replacement of alccofine is presented in the fig.3. From the results, it can be observed that as the percentage of alccofine increases, the slump value decreases. Higher percentages of alccofine tend to absorb more water. This attribute is due to the finer particle size of the alccofine which absorbs more water as a result of its increased surface area [7, 14, 15, 16].

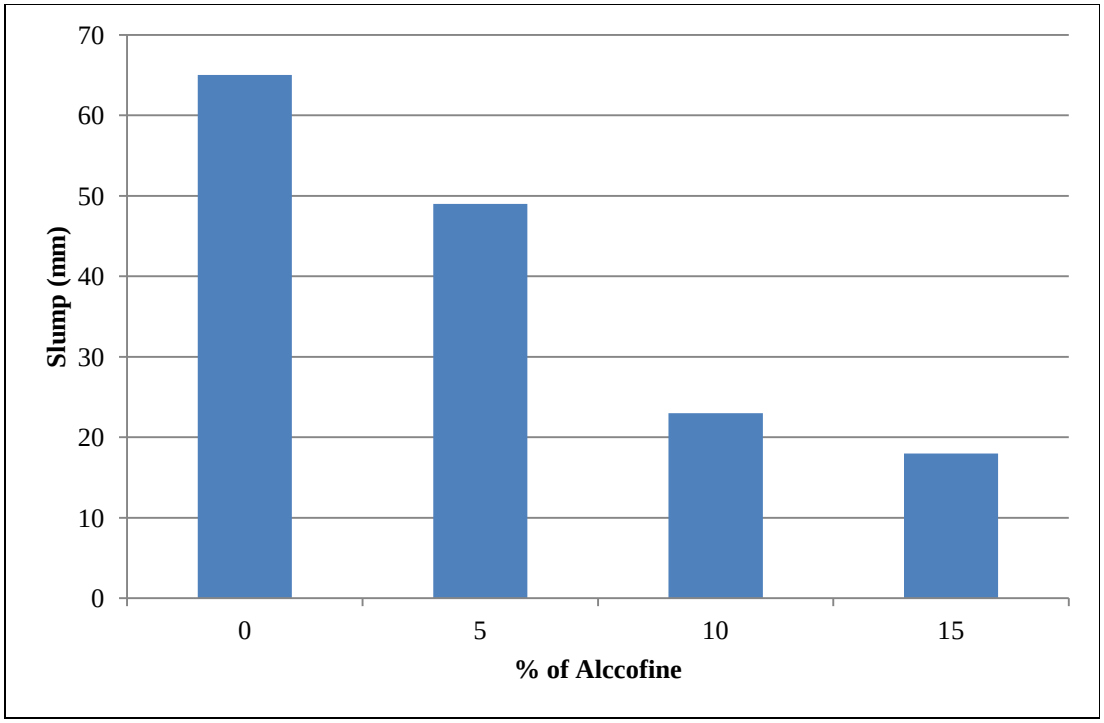

Fig.3. Slump of the concrete mixtures

4.2.Compressive Strength

Compressive strength of concrete for both grades of concrete at different ages of curing is shown in the table 4. Percentage improvement in the compressive strength of concrete upon different percentage replacements of alccofine compared to conventional concrete is presented in the fig. 4. For M25 grade concrete, the maximum improvement in strength of 14.68% was observed at 14 days and 13.62% at 90 days. Similarly for M40 grade concrete, the maximum improvement in strength of 13.01% at 14 days and 12.19% at 90 days was observed. This attribute is due to the increase in the fineness of the alccofine particles. Due to increase surface area as an attribute to increased fineness, the alccofine particles tends to fill up the voids in the concrete during mixing and compaction. This in turn results in the formation of a closely packed structure with lesser porosity, thereby improving the strength of the concrete [17, 18, 19]. But the improvement in the strength was not steady beyond 28 days, as there percentage of improvement compared to conventional concrete at 90 days is lesser compared to 28 days. This is because the formation of an inhibiting product after 28 days preventing further reaction of alccofine with the $Ca(OH)_2$. Also the reactivity of the alccofine was much effective till 28 days due to its pozzolanic activity which decreases the further improvement in the strength of concrete [15, 20].

Table 4. Compressive strength at different ages

No	Grade of the concrete	% of Alccofine	Compressive Strength (MPa)			
			7 days	14 days	28 days	90 days
1	M25	0	23.47	30.06	33.41	36.69
2		5	25.58	33.16	36.84	40.34
3		10	26.17	34.50	38.11	41.64
4		15	26.56	35.31	39.13	42.48
5	M40	0	31.86	43.23	48.04	52.91
6		5	34.61	47.49	52.61	57.72
7		10	35.72	48.83	54.15	59.21
8		15	36.14	49.67	55.21	60.26

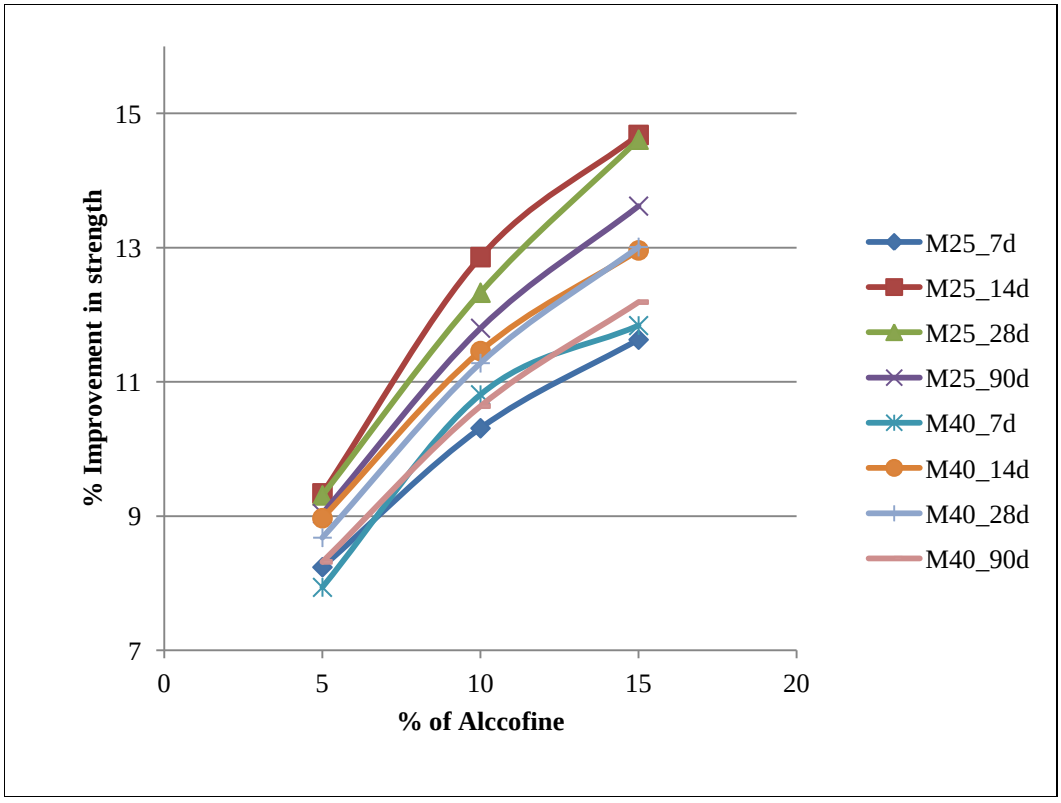

Fig.4. % Improvement in strength of concrete at different ages

4.3.Elastic Modulus

Elastic modulus of concrete for both grades of concrete at different ages of curing is shown in the table 5. It can be observed as the percentage of the alccofine is increased, the elastic modulus of concrete tend to increase for both grades of concrete and at all curing ages. Maximum improvement of 7.06% at 15% replacement for M25 grade concrete and 6.29% at 15% replacement for M40 grade concrete was observed at 90 days. No much variation in the improvement of elastic modulus at different grades of concrete was observed at 90 days. The micro-filler alccofine tends to fill up the voids in concrete forming a closely packed structure. Upon loading, the grain to grain transfer of load occurs as a result of which strain increases eventually at the rate of stress, thereby increasing the elastic modulus of concrete.

Table 5. Elastic modulus at different ages

No	**Grade of the concrete**	**% of Alccofine**	**Elastic Modulus (MPa)**	
			28 days	**90 days**
1	M25	0	28900.69	30286.13
2		5	30347.98	31756.88
3		10	30866.64	32264.53
4		15	31276.98	32588.34
5	M40	0	34655.44	36369.63
6		5	36266.37	37986.83
7		10	36793.34	38474.01
8		15	37151.71	38813.65

4.4.Autogenous shrinkage

Elastic modulus of concrete for both grades of concrete at 28 days in both sealed(S) and unsealed (US) conditions is shown in the fig 5. Maximum decrease in the shrinkage strain was observed for the sealed concrete specimens under compared to unsealed specimens. Also, as the

percentage of alccofine increases, the rate of shrinkage strain gets increased for both the grades of the concrete [21, 22, 23]. At M40 grade, the rate of shrinkage strain is more compared to M25 under all levels of replacement of alccofine. This is due to attribute of the increased cement content and reduced volume of aggregates. When the quantity of aggregates gets reduced, the restraining ability of aggregates against shrinkage of cement matrix gets reduced, thereby increasing the rate of shrinkage strain in concrete [15]. Also, increase in the percentage of alccofine increases the autogenous shrinkage of the concrete. This is due to the fact that at higher grades, alccofine tends to fill up the voids in the cement paste. This in turn increases the pressure over the cement paste and leading to further expansion of cement matrix. Such expansion of the cement matrix may cause micro-cracks in concrete affecting the durability properties of the concrete. So, excess addition of alccofine in higher grades concrete should be minimized to improve the durability properties of the concrete.

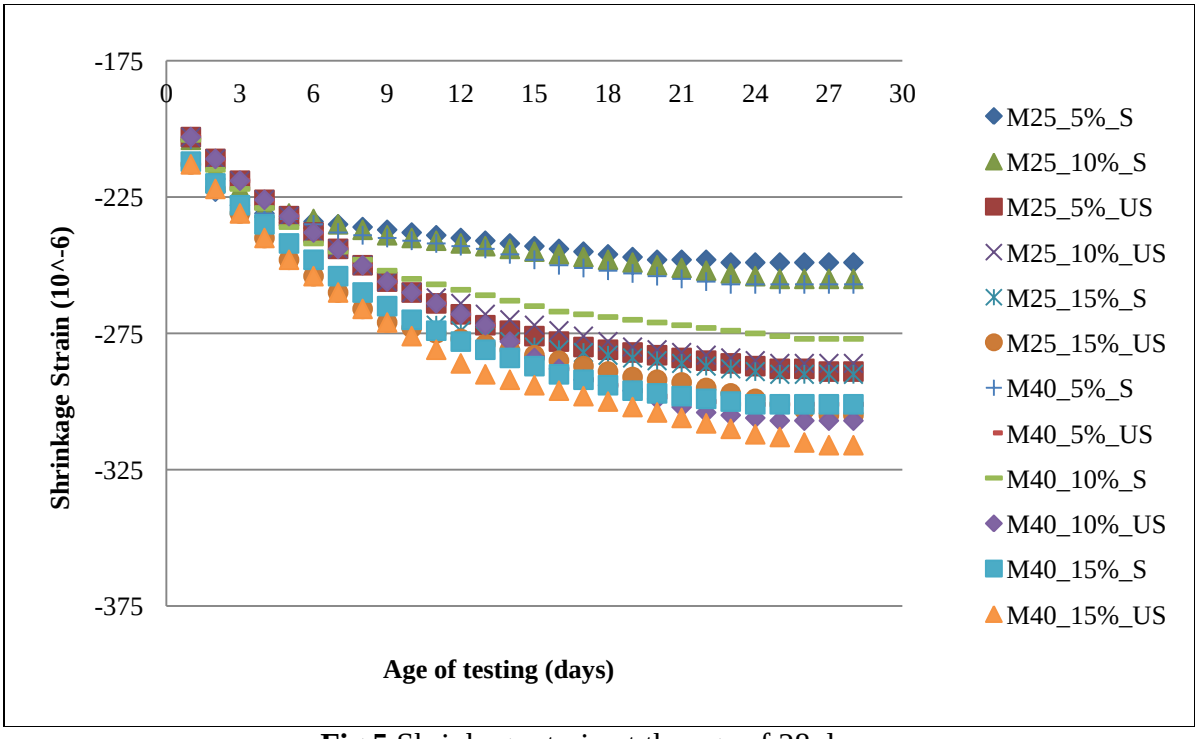

Fig.5. Shrinkage strain at the age of 28 days

4.5.Acid attack

Resistance of concrete against acid attack with different percentages of alccofine under both grades of concrete was presented in the fig.6. The maximum resistance to penetration of acids was observed at 15% replacement of alccofine in concrete for both M25 and M40 grade. Upon increase in the percentage of the alccofine, the rate of resistance to acid penetration gets reduced. This is due to pore filling ability of alccofine which fills up the voids in the concrete, thereby decreasing the rate of ingression of harmful acids into the concrete. Also, higher content of SiO_2 in alccofine reacts with $Ca(OH)_2$ from cement forming an impermeable C-S-H gel that reduces the rate of penetration of harmful acids thereby improving the durability of the concrete [24].

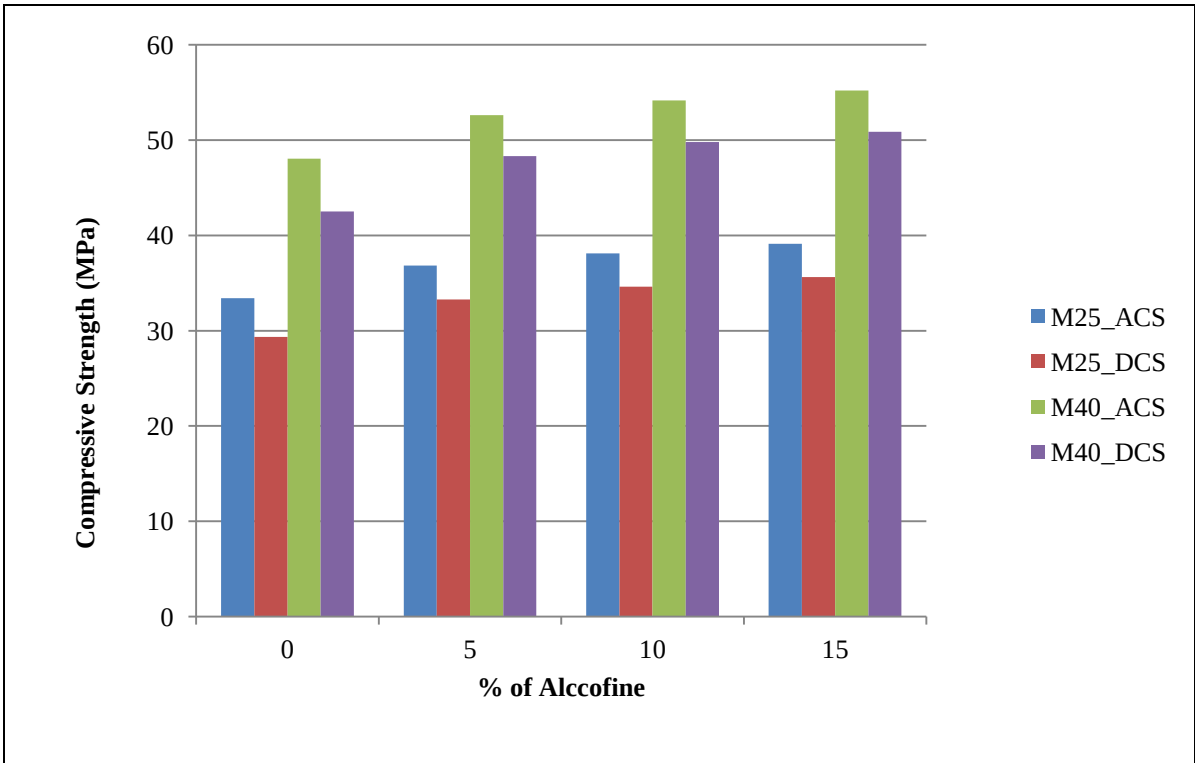

Fig.6.Resistance to acid attack

*ACS – Actual Compressive Strength; DCS – Decreased Compressive Strength

5. CONCLUSION

Based on the investigation on the performance of the alccofine at different levels of replacement, the following recommendations are made:

1. Increase in the percentage of alccofine decreases the workability of concrete as the finer alccofine having higher surface area tends to absorb more water reducing the slump value of the concrete.

2. As the percentage of alccofine increases, the compressive strength of the concrete increases irrespective to the grade of the concrete. Conversely, the percentage improvement in the strength of concrete upon addition of alccofine gets reduced due to its lesser pozzolanic reactivity at later ages.

3. The modulus of elasticity of concrete is not much dependent on the percentage of alccofine as no much variation was observed.

4. Autogenous shrinkage of concrete increases with the increase in the percentage of alccofine and it is more dependent on the grade of concrete.

5. Resistance of alccofine to acid increases as the percentage of alccofine increases.

6. REFERENCES

1. Lura P., Jenesen O M., Breugel K V. (2003), Autogenous shrinkage in high-performance cement paste. Cement and Concrete Research., 33, 223–232.

2. Hanumesh B M., Varun B K., Harish, B A. (2015), The mechanical properties of concrete incorporating silica fume as partial replacement of cement. International Journal of Emerging Technology Advanced Engineering., 5(9), 270- 275.
3. Katkhuda H., Hanayneh B., Shatarat N. (2009), Influence of silica fume on high strength light weight concrete. World Academy of Science Engineering and Technology., 34, 781-788.
4. Kumar R., Dhaka J. (2016), Partial replacement of cement with silica fume and effects on concrete properties. Int. J. Technol. Res. Eng., 4(1), 86-88.
5. Kadri E.H., Duval R. (1998), Influence of silica fume on the workability and compressive strength of high performance concrete. Cement and Concrete Research., 28(4), 533-547.
6. Khayat K H., Vachon M., Lanctot M C. (1997), Use of blended silica fumes cement in commercial concrete mixtures, ACI Materials Journal., 94(3), 183-192.
7. Wong H S., Razak H A. (2005), Efficiency of calcined kaolin and silica fume as cement replacement material for strength performance. Cement and Concrete Research., 35(4), 696-702.
8. Ramakrishnan V., Srinivasan V. (1982), Silica fume in fibre reinforced concrete. Indian Concrete Journal., 326-334.
9. Song H W., Pack S W., Jang J C., Saraswathy V. (2010), Estimation of permeability of Silica Fume cement concrete. Construction and Building Materials., 24(3), 315-521.
10. Sekharchi M., Rafiee A., Layssi H. (2009), Long-term chloride diffusion in Silica Fume Concrete in harsh marine climates. Cement and Concrete Composites., 31, 769-775.

11. Holt EE. (1998), Autogenous shrinkage at very early ages. Proceedings, International Workshop on Autogenous Shrinkage of Concrete, Japan Concrete Institute, Hiroshima, 133–140.
12. Kasai Y., Yokoyama K., Matsui I. (1972), Tensile properties of early age concrete. In: Mechanical behavior of materials. Society of Materials Science., 4, 288–99.
13. Neville A M., Dilger W H., Brooks J J. (1983), Creep of plain and structural concrete. London and New York: Construction Press.
14. Khatri R P., Sirivivatnanon V. (1995), Effect of different supplementary cementitious materials on mechanical properties of high performance concrete. Cement and Concrete Research., 25, 209–220.
15. Mazloom M., Ramezanianpour A A., Brooks J J. (2004), Effect of silica fume on mechanical properties of high-strength concrete. Cement and Concrete Composites., 26, 347-357.
16. Amarkhail, N. (2015), Effect of silica fume on properties of high strength concrete. Int. J. Tech. Res. Appl., 32, 13-19.
17. Shitole A. (2014), Use of micro-silica to improve the compressive and flexural strength of concrete. In Proceedings of Second IRF International Conference., Mysore, 43-45.
18. Hussain S T., Gopala Krishna Sastry K V A. (2014), Study of strength properties of concrete by using micro silica and nano silica. International Journal of Research in Engineering and Technology., 3(10), 103-108.
19. Ajileye F V. (2012), Investigations on Micro silica (Silica Fume) as partial cement replacement in concrete. Global Journal of Researches in Engineering., 12(1), 1-7.

20. Wild S., Sabir B B., Khatib J M. (1995). Factors influencing strength development of concrete containing silica fume. Cement and Concrete Research., 25(7), 1567–1580.
21. De Larrard F., Ithurralde G., Acker P., Chauvel D. (1990). High performance concrete for a nuclear containment. In Proceedings, Second International Symposium on Utilization of High-Strength Concrete, Berkley., 121–127.
22. Roy R. Larrard F. (1993). Creep and shrinkage of high performance concrete: the LCPC experience. In the Fifth International RILEM Symposium on Creep and Shrinkage of Concrete., London: E & FN Spon., 499–504.
23. Jensen O M., Hansen P F. (1999). Influence of temperature on autogenous deformation and relative humidity change in hardening cement paste. Cement and Concrete Research., 29, 567–75.
24. Sensualle G R. (2006). Strength development of concrete with rice-husk ash. Cement and Concrete Composites., 28(2), 2006.
25. IS: 8112-1989, Specifications for 43 grade Ordinary Portland Cement.
26. IS 456: 2000, Plain and Reinforced Concrete – Code of practice.
27. IS 10262: 2009, Guidelines for concrete mix design.
28. BS 1881: Part 116: 1983, Method of testing concrete.