Research Journal of Material Sciences ____ ISSN 2320–6055
Vol. **12(1),** 9-20, February **(2024)** *Res. J. Material Sci.*

Influence of carbon Nanotubes on mechanicals characteristiques of mortar and cement pastes

Sena Peace HOUNKPE[1], Valéry K. DOKO[2], Smith O. KOTCHONI[3], LI HUI[3] and Abbas T. DATCHOSSA[2*]
[1]Loboratory of Water Technical Sciences, UAC Benin
[2]Laboratory of Applied Energetics and Mechanics (LAEM), EPAC, UAC, 01 BP 2009 Cotonou, Benin
[3]Harbin Institute of Technology, Public University in Harbin, China
datchossatiamboabbas@gmail.com

Available online at: www.isca.in, www.isca.me
Received 19th March 2021, revised 19th May 2023, accepted 15th September 2023

Abstract

There is a rapid population explosion and a scientists' obligation to cater to the needs of this population. Furthermore, there is an urgent need to improve the strength of concrete and to reduce the production of cement. But cement is the world widly most used binder. That is why in this study we have evaluated the possibility to substituate cement by carbon nanotubes. To achieve this purpose, it has been manifactured mortars and cement pastes with different rates of substitution (0%, 0.1%, 0.5%, 1%) of cement by carbon nanotubes. The flexural and compressive strength have been determined before drawing a conclusion.

Keywords: Silicates; Flexural strength, compressive strength, cement, carbon nanotubes.

Introduction

Concrete is the material of present as well as future. The wide use of it in structures, from buildings to factories, from bridges to airports, makes it one of the most investigated material of the 21st century. Cement is the main constituent of it. Cement can be described as a crystalline compound of calcium silicates and other calcium compounds having hydraulic properties[1]. The big probleme is that construction, through the production of cement, occupies the second place in the production of CO_2 after industries[2]; in fact the manufacturing of one ton of PC, ~0.97 tons of CO2are released to the atmosphere, mainly due to the limestone calcinations to achieve the desired composition[3].

Due to the rapid population explosion and the technology boom to cater to these needs, there is an urgent need to improve the strength and durability of concrete. Then different materials known as supplementary cementitious materials are added to concrete improving its properties. Some of these are fly ash, blast furnace slag, rice husk, silica fumes and even bacteria. Those materials react with portlandite remaining in concrete[4,5] to improve it properties[6,7]. Of the various technologies in use, nano-technology looks to be a promising approach in improving the properties of concrete. In this article we are interested in improving the crack resistance, improving the mechanical properties of concrete. To do it we are going to use carbon nanotubes as supplementary cementitious materials.

Materials and Methods

Materials: General: This chapter is concerned with the details of the properties of the materials used, the method followed to design the experiment and the test procedures followed. The theory is supplemented with a number of pictures to have a clear idea of the methods.

Materials Properties: The materials used to design the mix for C30, C40, grade of concrete is cement, fly ash grade II, sand, coarse aggregate, water, Carbon Nanotube (CNT). The properties of these materials are presented below.

Properties of cement: Ordinary Portland cement (Chinese Standard GB 8076-2008) Classified As 42.5R was applied in this study. Chemical Composition, Mineral Composition, as well as Physical Performance of the cement, are shown in Table-1A. The contents of oxides were measured Through X-Ray Fluorescence. The Content of F-Cao was analyzed by the Franke Method. The mineral phases were calculated by The Bogue Method.

Fly Ash: The disposal of Fly ash poses increasingly difficult problems for many urbanized regions. A viable solution to the problem is reclamation of Fly ash for Civil Engineering applications. Previous researchersshown that fly ash is a potential source of construction material and soil stabilizer. Although it is one of the lowest cost and most widely used materials in the world, cement raises many concerns for the environment and human health. Many studies have been conducted with the aim of reducing the cost of cement for soil stabilization; one option is to partially replace cement with waste materials such as fly ash. This study we used Fly ash grade II.

Properties of sand: The China ISO Standard Sand Compiling with GB/T 17671-2005 was used to prepare cement Mortar.

Properties of Water: Tap water was used in this experiment. The properties are assumed to be same as that of normal water. Specific gravity is taken as 1.00. Pure water (deionized water) was used to make mortar specimen and cement paste.

Properties of Carbon walled Nanotubes: The Table-2 showed the properties of the Carbon nanotube.

Properties of Cement Paste and mortar: Cement paste and mortar are prepared with a water/cement ratio (w/c) of 0.32, using a blade-type high shear blender. Before mixing, polycarboxylate superplasticizers (PCE) solution was prepared with deionized water. With the addition of polycarboxylate super plasticizers (PCE) solution dosage 0.3% b.w.c., Cement paste was mixed for 2 min at low speed and then 2 min at high speed. The Table-1B and 2 showed the proportion and quantities of material used by following Chinese standard.

Mix calculations for mortar: The design of each mix began with a constant paste content (water + cement + supplementary cementitious materials) of 0.32 by weight of the total mix. The weight of cement and water was adjusted based on the specified water to binder ratio. The remainder of the mixture consisted of sand. Super plasticizer and air entraining agent were added based on experience and trial mixing prior to beginning the test program. The Table-3 and 4 showed detail the actual weights of the mixture components.

Table-1: Chemical and Mineral Compositions of Cement (Wt/%).

Chemical Composition (%)									Mineral Composition (%)				
Sio_2	Fe_2O_3	Al_2O_3	Cao	MgO	SO_3	FcaO	Cl^-	Na_2Oeq	LOSS	C_3S	C_2S	C_3A	C_4AF
20.560	3.230	4.600	62.560	2.570	2.950	0.870	0.011	0.530	2.040	57.340	18.900	6.470	11.250

Table-2: Properties of Carbon nanotube.

Test Item	values
Weight	100g
OD	50nm
Length	<10um
Purity	>98wt%
MFG CODE	TNM8 171127

Table-3A: Mixture proportions with W/C ratio 0.32 for Cement Paste without fly ash.

Cement Paste type		water(g)	Cement (g)	Carbon nanotubes (g)	Water reducing agent (g)	Test pieces
Pure Cement Paste	PO	1664	5200		5.4	12
Carbon nanotubes (CNT)	C001	1664	5200	0.52	5.4	12
	C005	1664	5200	2.6	5.4	12
	C01	1664	5200	5.2	5.4	12
Total dosage		6656	20800	8.32	21.6	48

Table-3B: Mixture proportions with W/C ratio 0.32 for Cement Paste content fly ash.

Cement Paste type		water(g)	Cement (g)	Fly Ash	CNT (g)	Water reducing agent (g)	Test pieces
Pure Cement Paste	P0	1664	4160	1040	-	5.4	12
Carbon nanotubes (CNT)	C001	1664	4160	1040	0.52	5.4	12
	C005	1664	4160	1040	2.6	5.4	12
	C01	1664	4160	1040	5.2	5.4	12
Total dosage		6656	16640	4160	8,32	21,6	48

Test Procedures: Curing Regimens: The specimens remained in their molds for 24 hours at room temperature, 25°C. The Specimens tested were generally curing with air cured at 25°C and RH 92% for 3days, 7 days and 28 days.

Testing: Testing procedures used to evaluate compressive strength and flexural strength are presented in this section.

Flexural Strength Test for Mortar and cement paste: Flexural testing machine Reference number YAW-300 was used. Flexural strength was evaluated according to Chinese standard with the software Super Test version 8 and the load rate was 50 N/s. Prismatic specimens with dimensions of 40mm x 40mm x 160mm were loaded using a third point loading setup across their strong axis. Three specimens from each batch were tested at an age of 3, 7, and 28 days and the mean Flexural strength of three specimens is considered as the Flexural strength of the specified category.

Compressive Strength Test for Mortar and cement paste: Compressive testing machine Reference number YAW-300 was used after 3, 7, and 28 days of curing with surface dried condition as per Chinese Standard. The compressive strength of specimens is determined with the software Super Test version 8 and the load rate was 2.4 KN/s. Three specimens are tested for typical category and the mean compressive strength of three specimens is considered as the compressive strength of the specified category.

Results and Discussion

This chapter is concerned with the presentation of results of the experiments carried out towards the objective of the article.

Comparison Results and Analysis of mechanical test: Comparison of Compressive Strength and flexural strength Results for cement paste and mortar: The change in compressive strength and flexural strength for the blended sample (in %) for 3, 7 and 28 days is shown respectively in the Table-5,6,7. A graphical representation of this result is shown respectively in the Figure-1,2,3.

Table-4A: Mixture proportions with W/C ratio 0.32 for Mortar discontent fly ash.

Mortar type		Water (g)	Cement (g)	Sand (g)	CNT (g)	Water reducing agent (g)	Test pieces
Pure Mortar	PO	576	1800	5400		5.4	12
Carbon nanotubes CNT	C001	576	1800	5400	0.18	5.4	12
	C005	576	1800	5400	0.9	5.4	12
	C01	576	1800	5400	1.8	5.4	12
Total dosage		2304	7200	21600	2.88	21.6	48

Table-4B: Mixture proportions with W/C ratio 0.32 for Mortar content fly ash.

Mortar type		Water (g)	Cement (g)	Fly Ash (g)	Sand (g)	CNT (g)	Water reducing agent (g)	Test pieces
Pure Mortar	PO	576	1440	360	5400		5.4	12
Carbon nanotubes CNT	C001	576	1440	360	5400	0.18	5.4	12
	C005	576	1440	360	5400	0.9	5.4	12
	C01	576	1440	360	5400	1.8	5.4	12
Total dosage		2304	5760	1440	21600	2.88	21.6	48

Table-5: Comparison mechanical Strength of Mortar specimen without Fly Ash at 3-day test.

Type	Flexural	Increase in Strength (%)	Compressive	Increase in Strength (%)
PO	8.4	-	38.26	-
C001	7.77	-7.5	41.44	8.31
C005	6.4	-23.8	40.79	6.61
C01	6.2	-26.19	36.54	-4.48

Table-6: Comparison mechanical Strength of Mortar Specimen without Fly Ash at 7-day test.

Type	Flexural	Increase in Strength (%)	Compressive	Increase in Strength (%)
PO	9.67	-	40,94	-
C001	9.07	-6.2	53,87	31.58
C005	7.73	-20.06	49,35	20.54
C01	7.4	-23.47	39,1	-4.49

Table-7: Comparison mechanical Strength of Mortar Specimen without Fly Ash at 28-day test.

Type	Flexural	Increase in Strength (%)	Compressive	Increase in Strength (%)
PO	10.1	-	59.55	-
C001	10.3	1.98	69.04	15.94
C005	9.9	-1.98	65.48	9.96
C01	9.13	-9.60	57.82	-2.91

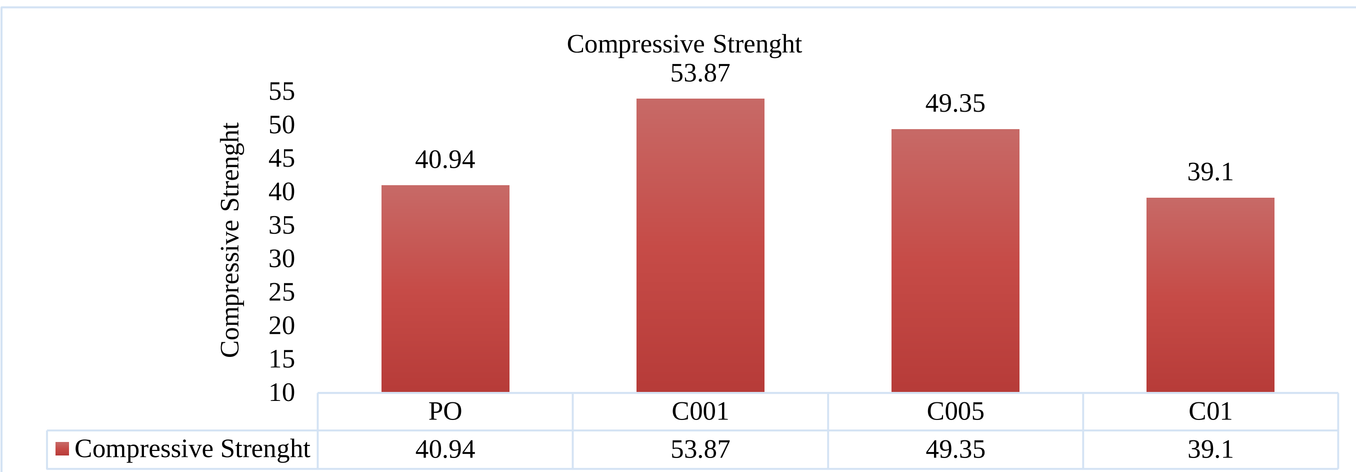

Figure-1: 3 Day test Mortar Specimen without Fly Ash.

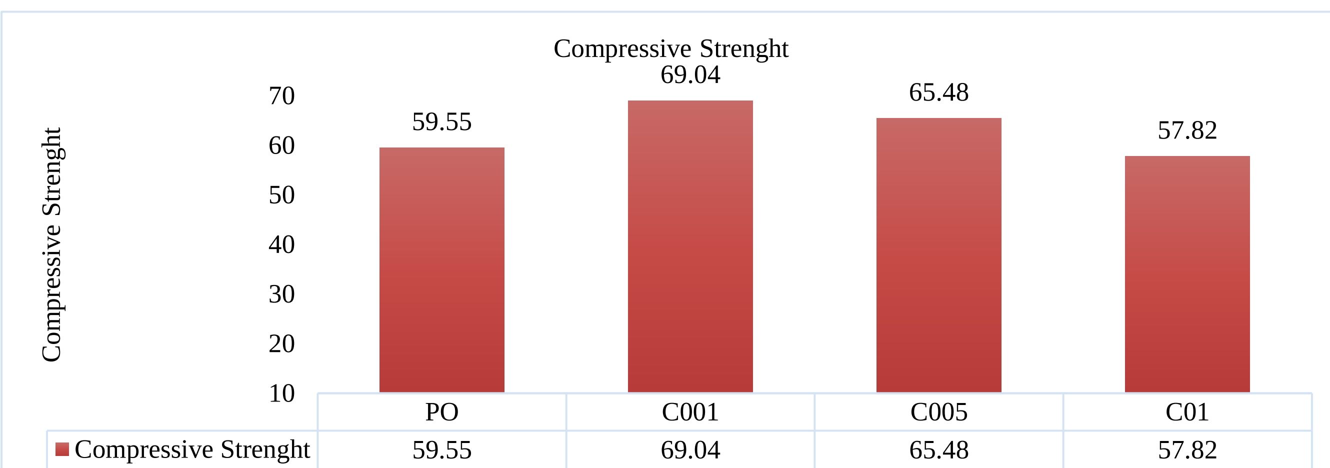

Figure-2: 7 Day test Mortar Specimen without Fly Ash.

The Table-5,6,7 show a good increase of compressive strength when we use C001 and C005 (without Fly Ash) with a better result in using C001. The increase in compressive strength is due to the changing of the portlandite into silicates[8,9]. Moreover, the small size of nanotubes makes them to fill voids in the material[10]. Contrary to compressive strength, we have a loss of flexural strength when we use each of the three Carbon nanotubes (without Fly Ash). The diagrams (Figure-1,2,3) show the real evolution of the compressive strength.

The Figure-4 shows that, from 3 days to 28 days, the compressive strength evolution curve when we use C001 is up all the overs. Then, the best Carbon Nanotube to increase the compressive strength (without fly ash) is the C001.

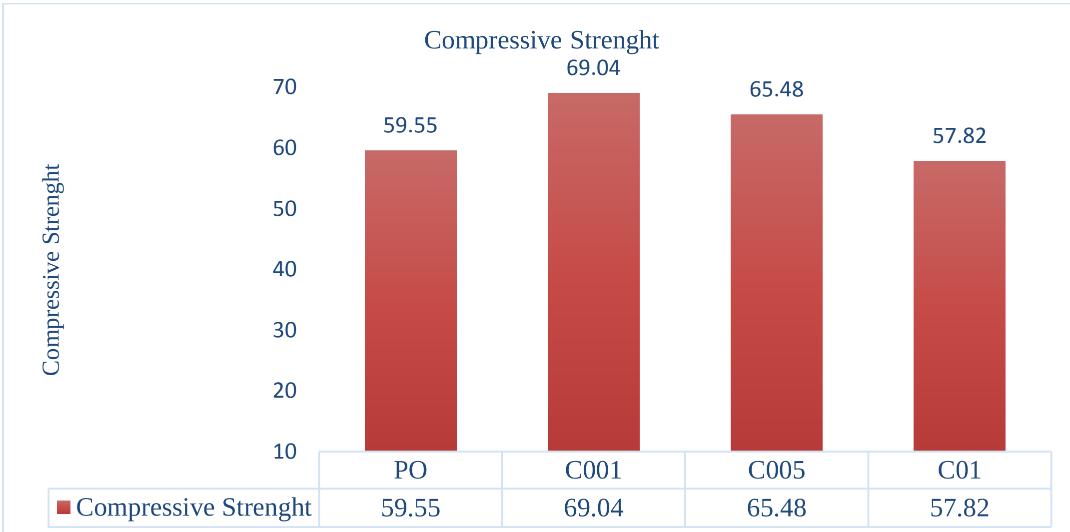

Figure-3: 28 Day test Mortar Specimen without Fly Ash.

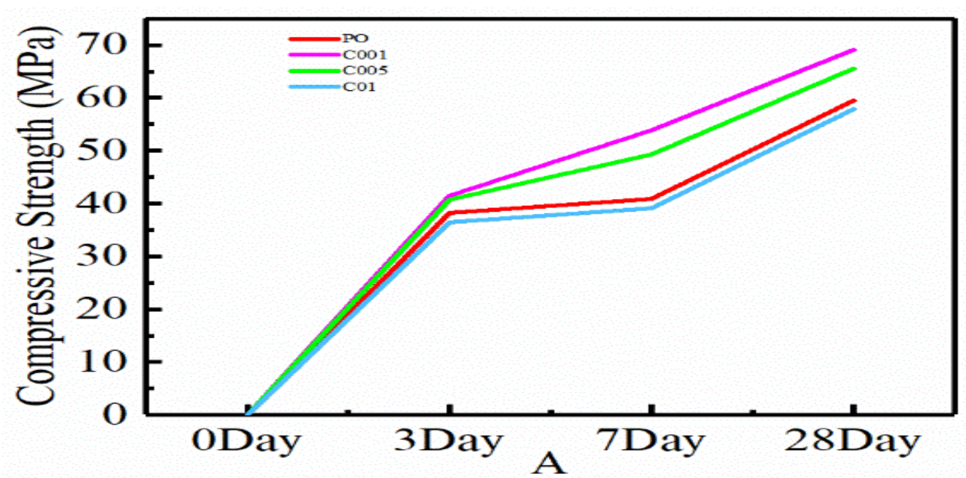

Figure-4: Change in Compressive Strength of Mortar Specimen without Fly Ash from 3 Day to 28 Days.

Table-8: Comparison mechanical Strength of Mortar Specimen with Fly Ash at 3-day test.

Type	Flexural	Increase in Strength (%)	Compressive	Increase in Strength (%)
PO	6.4	-	28.38	-
C001	5.6	-12.50	30.92	8.96
C005	5.8	-9.38	30.44	7.25
C01	5.7	-10.94	27.27	-3.91

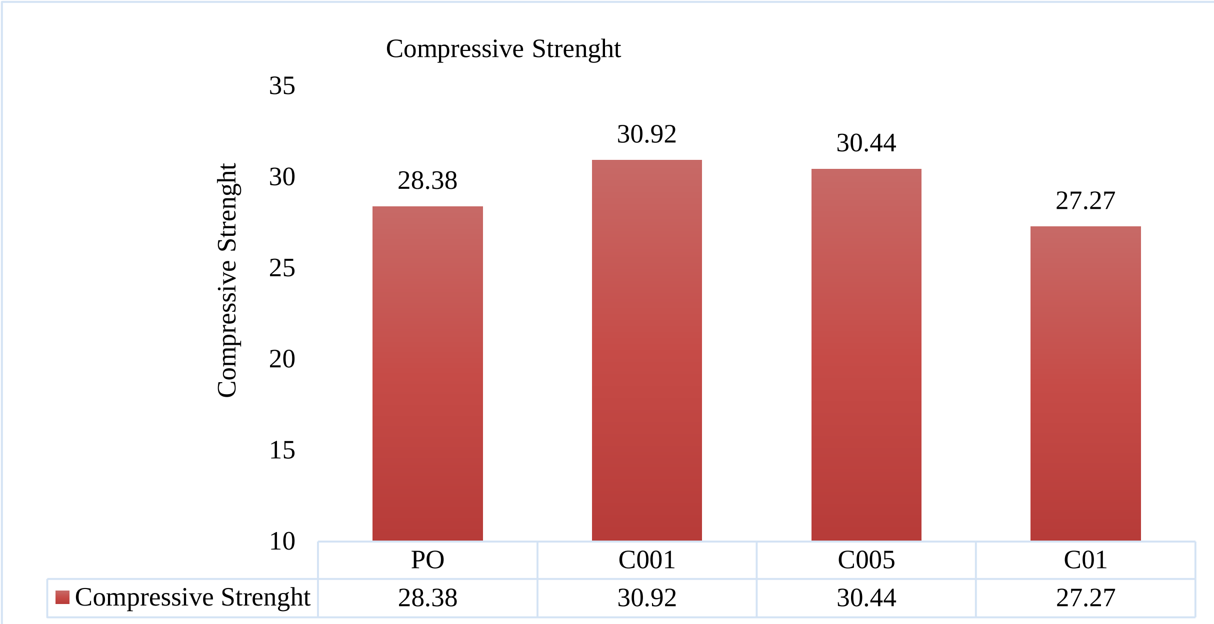

Figure-5: 3 Day test Mortar Specimen with Fly Ash.

Table-9: Comparison mechanical Strength of Mortar Specimen with Fly Ash at 7-day test.

Type	Flexural	Increase in Strength (%)	Compressive	Increase in Strength (%)
PO	7.53	-	31.98	-
C001	7.13	-5.31	42.08	31.60
C005	6.87	-8.76	38.55	20.56
C01	7.67	1.86	30.58	-4.38

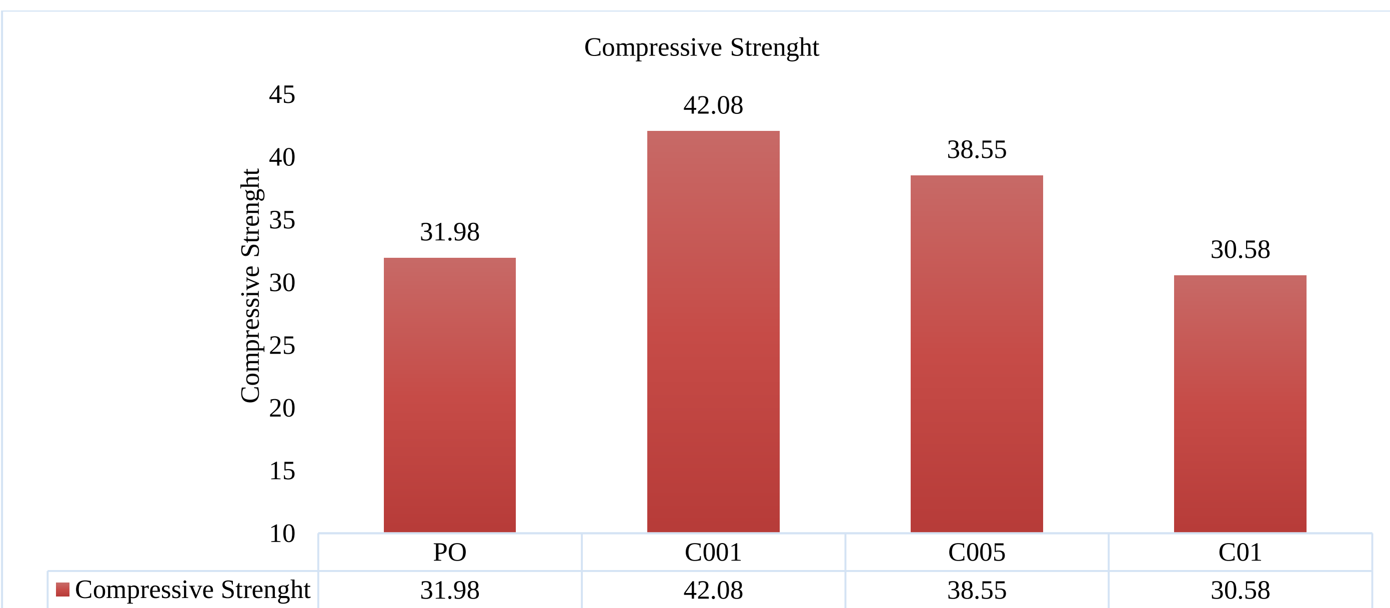

Figure-6: 7Day test Mortar Specimen with Fly Ash.

The Table-8,9,10 show a good increase of compressive strength of mortar when we use C001 and C005 (with Fly Ash) with a better result in using C001. This increase of compressive strength is due to the reaction of the carbon nanotubes on the portlandite to change it into to silicates[8,9]. It is seen that all the fly ash samples present lower mechanical properties than the discontent fly ash samples. These results are obviously due to a lesser amount of cement in all mixes containing both fly ash and carbon nanotubes[11,12]. Contrary to compressive strength, we have a loss of flexural strength when we use each of the three Carbon nanotubes (with Fly Ash). The diagrams (Figure-5,6,7) show the real evolution of the compressive strength.

The Figure-8 shows that, from 3days to 28days, the mortar compressive strenght evolution curve when we use C001 is up all the overs. Then, the best rate of Carbon Nanotube to increase the mortar compressive strength (with fly ash) is the C001.

Table-10: Comparison mechanical Strength of Mortar Specimen with Fly Ash at 28-day test.

Type	Flexural	Increase in Strength (%)	Compressive	Increase in Strength (%)
PO	9.5	-	54.14	-
C001	8.73	-8.11	62.76	15.94
C005	8.53	-10.21	59.53	9.96
C01	9.56	0.63	52.56	-2.91

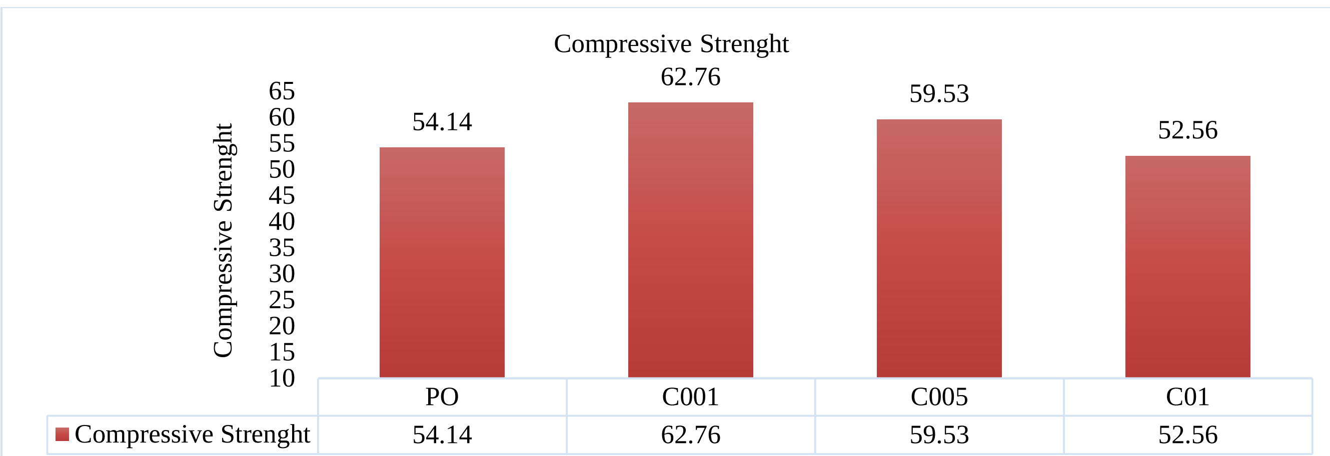

Figure-7: 28Day test Mortar Specimen with Fly Ash.

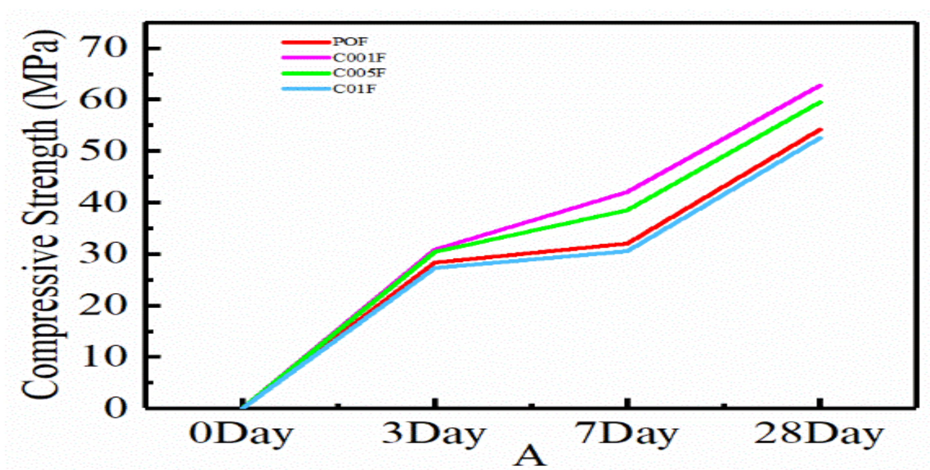

Figure-8: Change in Compressive Strength of Mortar Specimen with Fly Ash from 3 Day to 28 Days.

Table-11: Comparison mechanical Strength of Cement Paste Specimen without Fly Ash at 3-day test

Type	Flexural	Increase in Strength (%)	Compressive	Increase in Strength (%)
PO	7.5	-	38.6	-
C001	9.4	25.33	43.97	13.91
C005	8.4	12.00	43.32	12.23
C01	7	-6.67	38.88	0.73

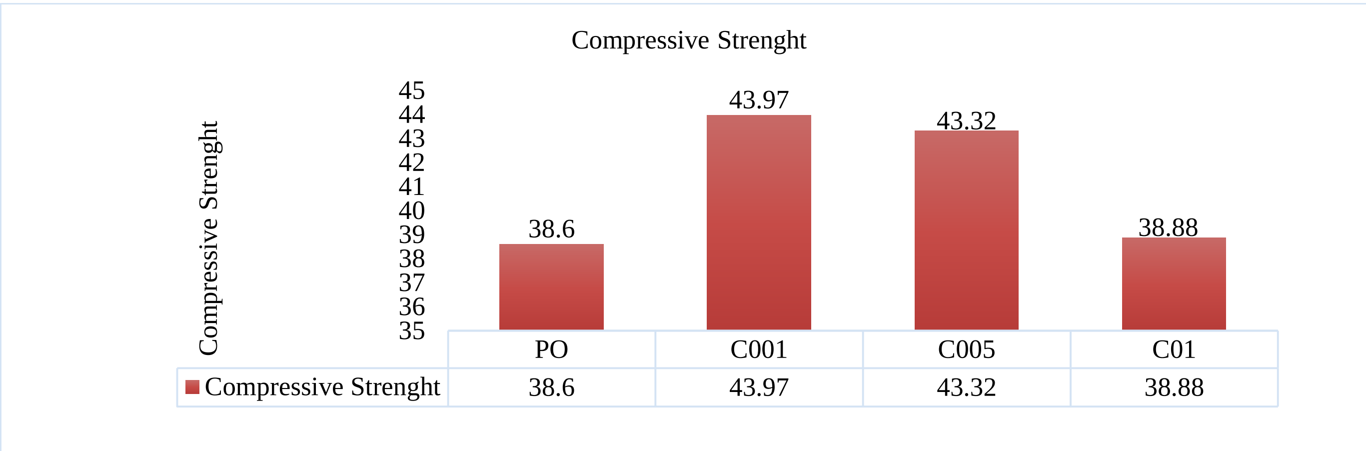

Figure-9: 3 Day test Cement Paste Specimen without Fly Ash.

Table-12: Comparison mechanical Strength of Cement Paste Specimen without Fly Ash at 7-day test

Type	Flexural	Increase in Strength (%)	Compressive	Increase in Strength (%)
PO	8.4	-	41.68	-
C001	11.3	34.52	57.50	37.96
C005	10.9	29.76	52.67	26.36
C01	7.8	-7.14	41.75	0.17

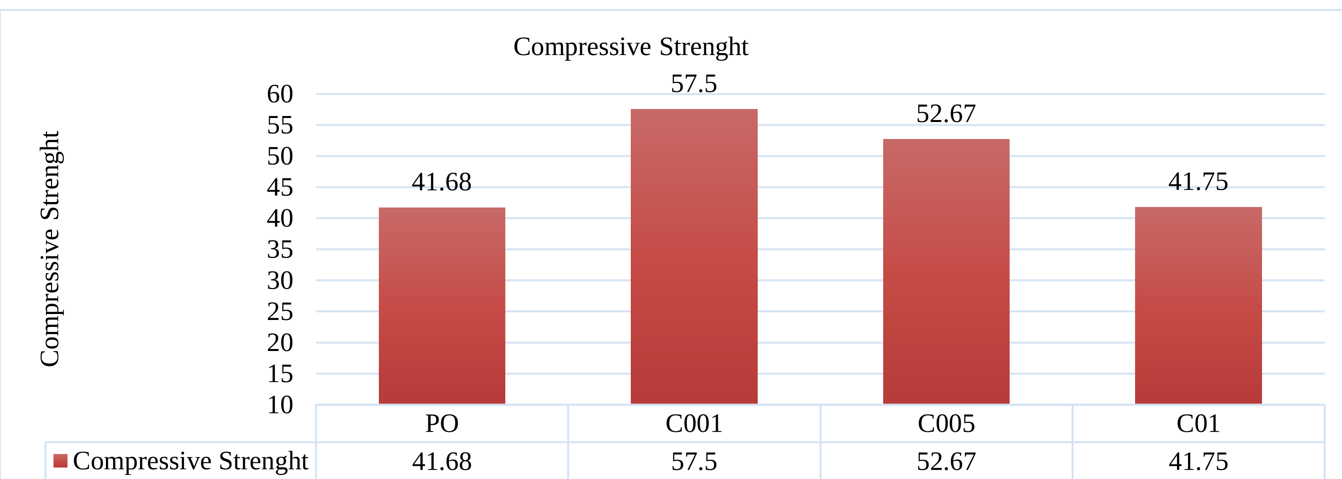

Figure-10: 7-Day test Cement Paste Specimen without Fly Ash.

The Table-11,12,13 show a good increase of the Cement Paste compressive and flexural strength when we use C001 and C005 (without Fly Ash*)* with a better result in using C001. The increase in compressive and flexural strength is due to the changing of the portlandite into silicates[8,9].

The formation of supplementary silicates helps to bridge hydratation compounds and thus improve flexural strength[13].

The diagrams Figure-9,10,11 show the real evolution of the compressive strength.

The Figure-12 shows that, from 3 days to 28 days, the Cement Paste compressive strenght evolution curve when we use C001 is up all the overs. Then, the best rate of Carbon Nanotube to increase the Cement Paste compressive strength (without fly ash) is the C001.

Table-13: Comparison mechanical Strength of Cement Paste Specimen without Fly Ash at 28-day test.

Type	Flexural	Increase in Strength (%)	Compressive	Increase in Strength (%)
PO	9.9	-	63.6	-
C001	14	41.41	73.2	15.07
C005	13.4	35.35	69.5	9.24
C01	8.9	-10.10	62.0	-2.45

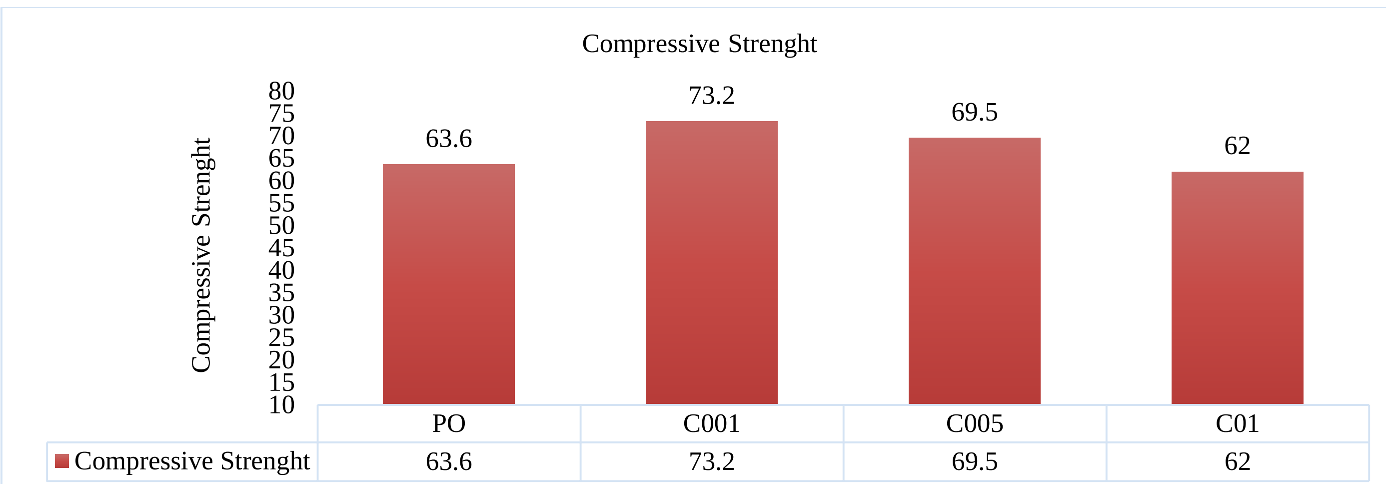

Figure-11: 28Day test Cement Paste Specimen without Fly Ash.

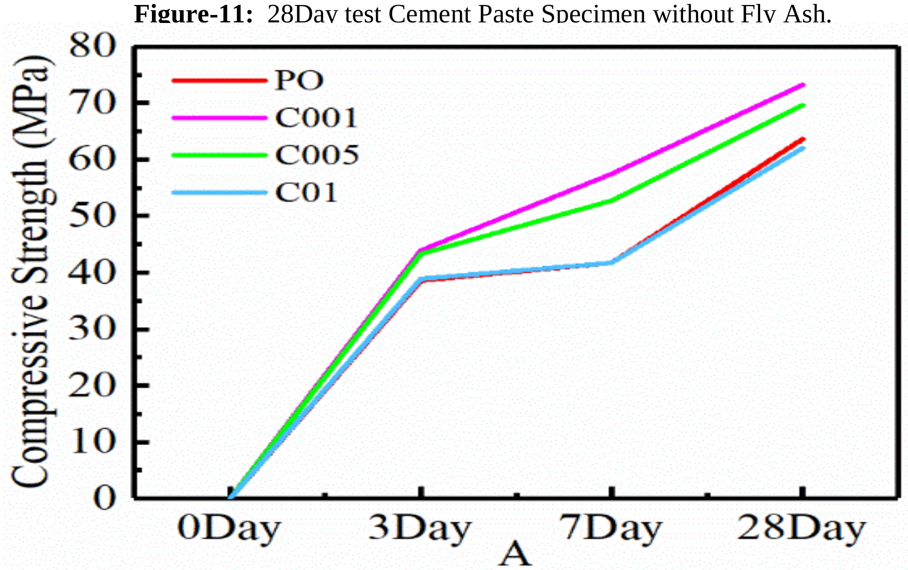

Figure-12: Change in Compressive Strength of Cement Paste Specimen without Fly Ash from 3 Day to 28 Days.

Table-14: Comparison mechanical Strength of Cement Paste Specimen with Fly Ash at 3-day test.

Type	Flexural	Increase in Strength (%)	Compressive	Increase in Strength (%)
PO	6.5	-	28.9	-
C001	8.6	32.31	31.5	8.96
C005	8.2	26.15	31.0	7.25
C01	6.5	0.00	27.8	-3.91

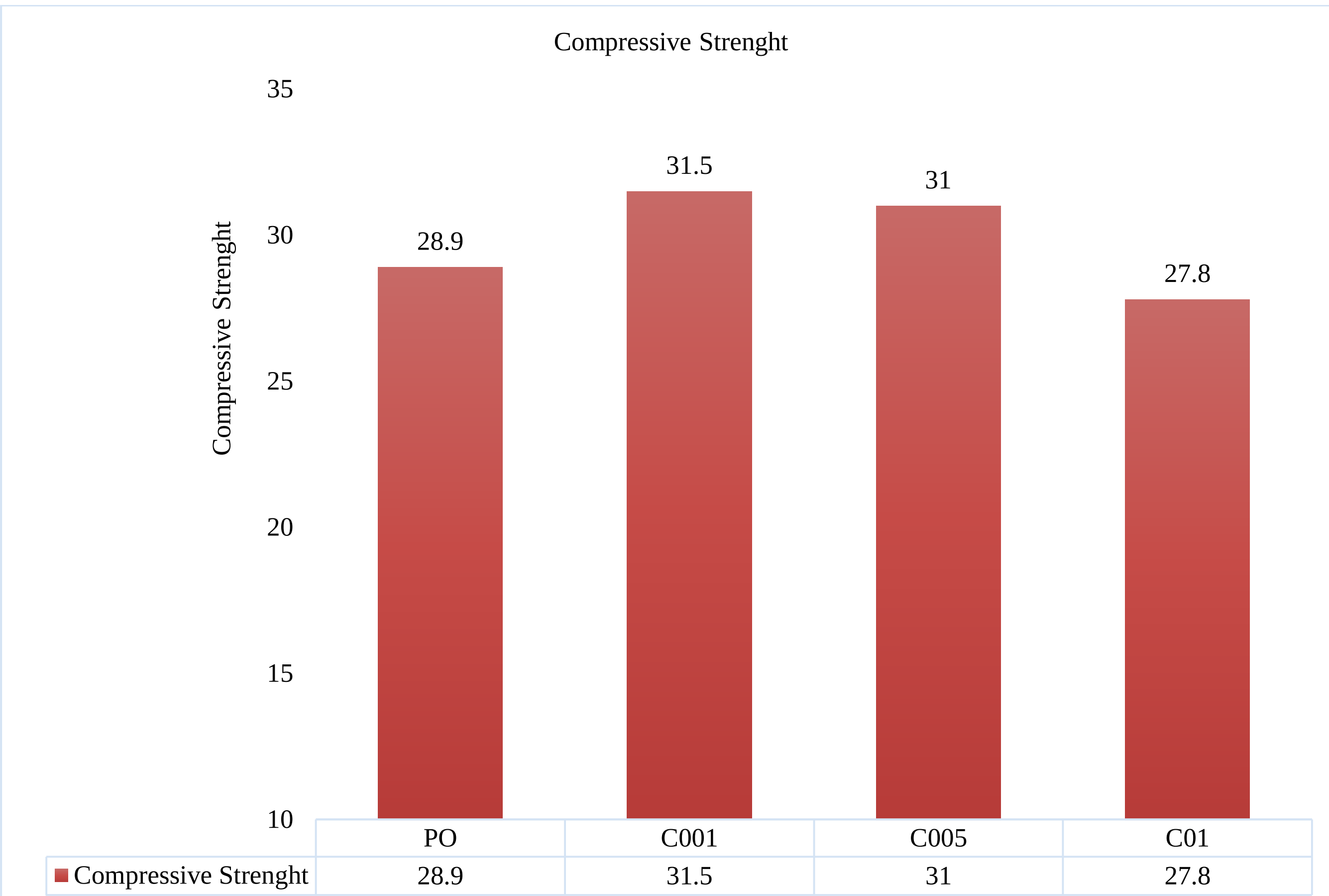

Figure-13: 3 Day test Cement Paste Specimen with Fly Ash.

Table-15: Comparison mechanical Strength of Cement Paste Specimen with Fly Ash at 7-day test.

Type	Flexural	Increase in Strength (%)	Compressive	Increase in Strength (%)
PO	7.9	-	43.2	-
C001	10	26.58	56.8	31.60
C005	9.5	20.25	52.0	20.56
C01	7	-11.39	34.5	-19.99

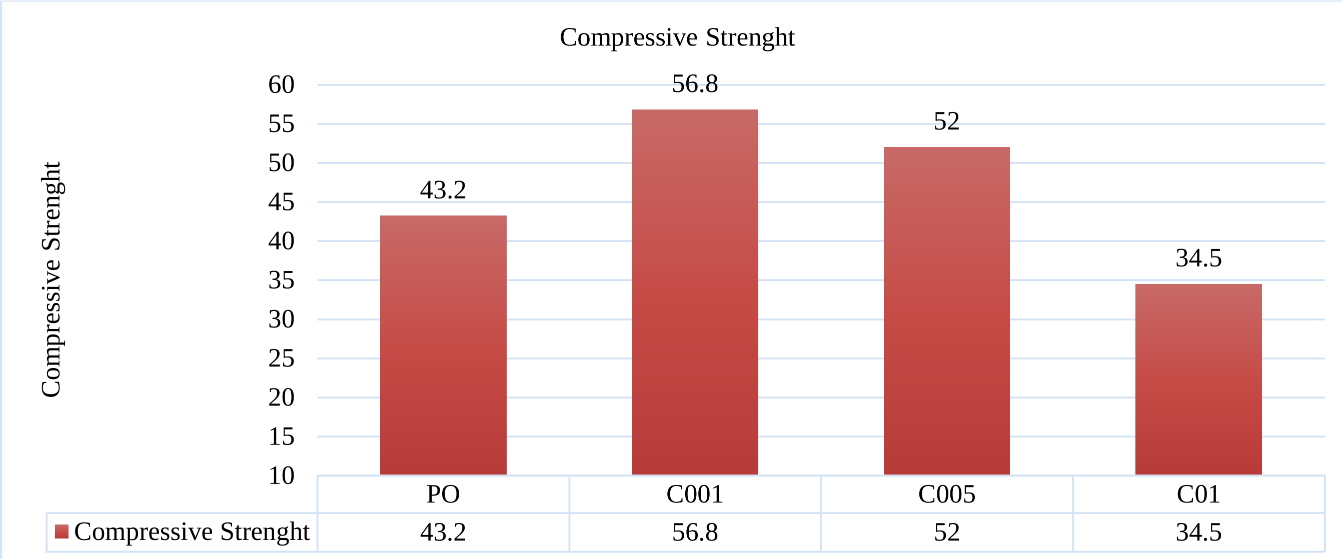

Figure-14: 7-Day test Cement Paste Specimen with Fly Ash.

Table-16: Comparison mechanical Strength of Cement Paste Specimen with Fly Ash at 28-day test.

Type	Flexural	Increase in Strength (%)	Compressive	Increase in Strength (%)
PO	9	-	55.8	-
C001	12.4	37.78	64.6	15.94
C005	11.4	26.67	61.3	9.96
C01	8.2	-8.89	54.1	-2.91

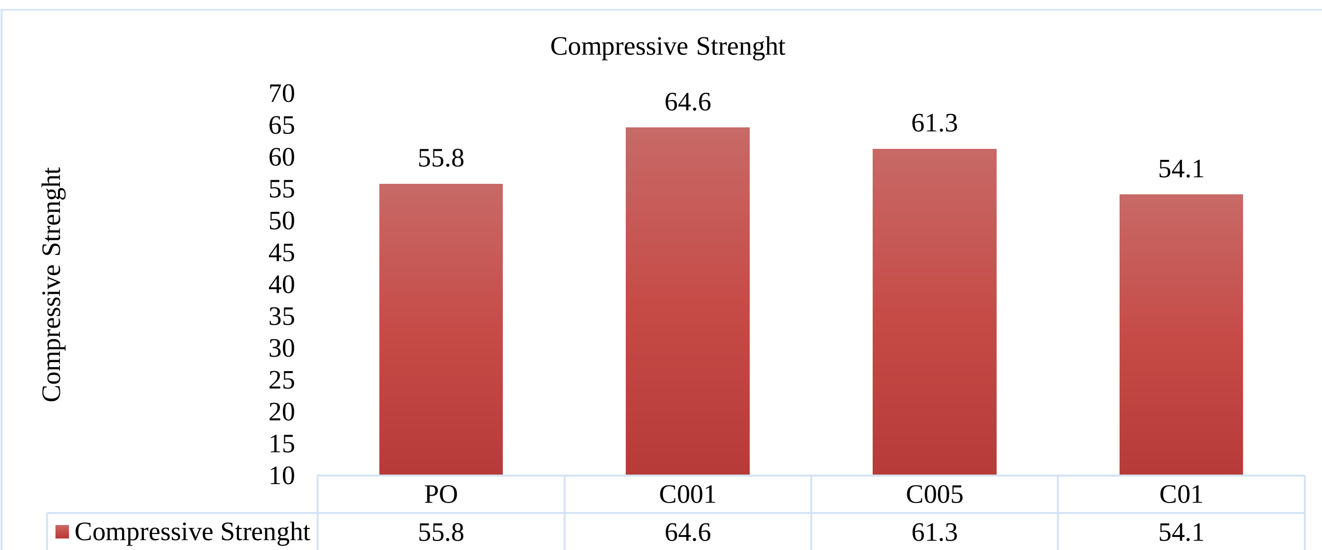

Figure-15: 28 Day test Cement Paste Specimen with Fly Ash.

The Table-14,15,16 show a good increase of the Cement Paste compressive and flexural strength when we use C001 and C005 (without Fly Ash*)* with a better result in using C001. The increase in compressive and flexural strength is due to the changing of the portlandite into silicates[8,9]. The formation of supplementary silicates helps to bridge hydratation compounds and thus improve flexural strength[13]. It is noticed that all the fly ash samples present lower mechanical properties than the discontent fly ash samples. These results are obviously due to a lesser amount of cement in all mixes containing both fly ash and carbon nanotubes[11,12]. The Figure-13,14,15 show the real evolution of the Cement Paste compressive strength (with Fly Ash).

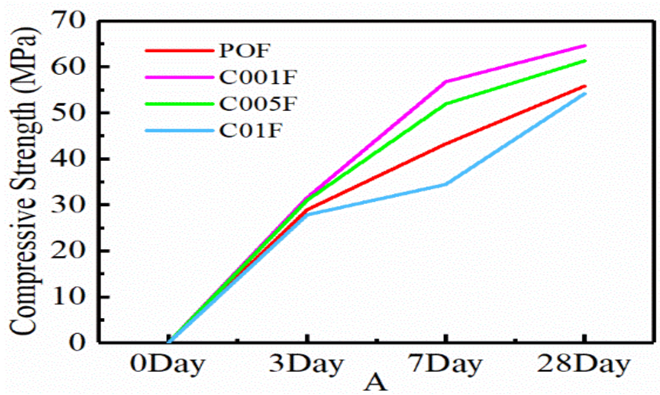

Figure-16: Change in Compressive Strength of Cement Paste Specimen with Fly Ash from 3 Day to 28 Days.

The figure 16 shows that, from 3days to 28days, the Cement Paste compressive strength evolution curve when we use C001 is up all the overs. Then, the best rate of Carbon Nanotube to increase the Cement Paste compressive strength (with fly ash) is the C001.

Conclusion

The study showed that: The use of carbon nanotubes gives very interesting resultswhen the purpose is to increase compressive strength of cementitious materials specially when we use C001 or C005. The best rate of carbon nanotube to increase compressive strength of cementitious materials recommended is the C001. Contrary to compressive strength, we have a loss of flexural strength when we use Carbon nanotubes.

References

1. Meason M. (1981). Etude de l'activitépouzzolanique des matériaux naturels ettraités thermiquement en vue de laréalisation des liants hydrauliques. Thèse Doctorat, Université Paul Sabatier, Toulouse. 133-145.
2. Bidjocka, C., Tusset, J., Messi, A., & Perra, J. (1993). Etude et évaluation de l'activité pouzzolanique des pouzzolanes de Djoungo (Cameroun). Annales de la Faculté des Sciences de l'Université de Yaoundé, 133-145.
3. Hossain, M. M., Karim, M. R., Hossain, M. K., Islam, M. N., & Zain, M. F. M. (2015). Durability of mortar and concrete containing alkali-activated binder with pozzolans: A review. *Construction and Building Materials*, 93, 95-109.
4. Shi, C., & Day, R. L. (2001). Comparison of different methods for enhancing reactivity of pozzolans. *Cement and Concrete Research*, 31(5), 813-818.
5. Shaheen, E., & Shrive, N. G. (2006). Optimization of mechanical properties and durability of reactive powder concrete. *ACI Materials Journal*, 103(6), 444.
6. Wen-yu, J., Ming-zhe, A., Gui-ping, Y., & Jun-min, W. (2004). Study on reactive powder concrete used in the sidewalk system of the Qinghai-Tibet railway bridge. In International Workshop on Sustainable Development and Concrete Technology, Beijing, China. pp. 333-338.
7. Piérard, J., Dooms, B., & Cauberg, N. (2012). Evaluation of durability parameters of UHPC using accelerated lab tests. In *Proceedings of the 3rd International Symposium on UHPC and Nanotechnology for High Performance Construction Materials, Kassel, Germany*, pp. 371-376.
8. Gonzalez-Corominas, A., Etxeberria, M., & Poon, C. S. (2016). Influence of steam curing on the pore structures and mechanical properties of fly-ash high performance concrete prepared with recycled aggregates. *Cement and Concrete Composites*, 71, 77-84.
9. Cheyrezy, M., Maret, V., & Frouin, L. (1995). Microstructural analysis of RPC (reactive powder concrete). *Cement and concrete research*, 25(7), 1491-1500.
10. Hu, Y., Luo, D., Li, P., Li, Q., & Sun, G. (2014). Fracture toughness enhancement of cement paste with multi-walled carbon nanotubes. *Construction and Building Materials*, 70, 332-338.
11. Khan, K., Amin, M. N., Saleem, M. U., Qureshi, H. J., Al-Faiad, M. A., & Qadir, M. G. (2019). Effect of fineness of basaltic volcanic ash on pozzolanic reactivity, ASR expansion and drying shrinkage of blended cement mortars. *Materials*, 12(16), 2603.
12. Douaissia, Z., & Merzoud, M. (2018). Effect of mineral admixtures on the rheological and mechanical properties of mortars. *In MATEC Web of conferences*, 149, 01066. EDP Sciences.
13. Evangelista, A. C. J., de Morais, J. F., Tam, V., Soomro, M., Di Gregorio, L. T. & Haddad, A. N. (2019). Evaluation of carbon nanotube incorporation in cementitious composite materials. *Materials*, 12(9), 1504.