EXPERIMENTAL INVESTIGATION ON CONCRETE CONTAINING NANO-METAKAOLIN

Aiswarya S
Lecturer
School of Civil Engineering
Karunya University
Coimbatore, Tamil nadu
India

Prince Arulraj G
Professor and Dean
Department of Civil Engineering
SNS College of Technology
Coimbatore, Tamil nadu
India

Anand Narendran
Former PG Student
School of Civil Engineering
Karunya University
Coimbatore, Tamil nadu
India

Abstract: **Nanotechnology is one of the most promising areas of science. The concept of use of nano particles in concrete is one of the new revolutionary steps in concrete technology.In this paper, an attempt has been made to understand the influence of Nano- Metakaolin as a partial replacement substance for cement in concrete. An experimental investigation has been carried out to determine the compressive strength, split tensile strength and modulus of elasticity of normal cement concrete and concrete containing Nano-Metakaolin partially replacing cement at various percentages. The mixes were designed as per IS 10262-2009. The cement was replaced by Nano- Metakaolin at various percentages (2%, 4%, 6%, 8%, 10%, 12%, 14%, 16%, 18% and 20%) for M20, M30, M40 and M50 grades. A comparison between the cost of Normal Concrete and concrete with Nano-Metakaolin is also made. It is found that partial replacement of cement with Nano-Metakaolin has a greater influence on the strength of concrete. The optimum percentage at which cement can be replaced with Nano-Metakaolin is found to be 10%.**

Keywords: **Nano particles, Nano - Metakaolin, Normal Cement Concrete, Compressive strength, Tensile strength.**

I. INTRODUCTION

Concrete is a newer construction material compared to steel and stone. Use of concrete in constructions and buildings might have begun less than a century ago. In the past few decades, many researchers have used wide range of supplementary materials like pozzolanas and nano particles. Trass, zeolite, volcanic tuff, metakaolinite and burned clay are some of the naturally occurring pozzolanas. Silica fume, fly ash and blast furnace slag are some of the artificial pozzolanas. The use of additional cementitious materials due to economic, technical and environmental considerations has become very common in modern concrete construction.

A number of studies have been conducted on the durability and strength of concrete made with mineral admixtures. Metakaolin differs from the more commonly used mineral admixtures, such as fly ash and silica fume, that it is not a by-product. It is manufactured under controlled conditions by heating kaolin, one of the most abundant natural clay minerals, to temperatures of 650-900°C. The resulting anhydrous alumino-silicate ($Al_2Si_2O_7$) also represented as AS_2 is mainly amorphous in nature and behaves as a highly reactive artificial pozzolana. Recently, nano technology has attracted great scientific attention because of the new potential uses of particles in nano metre (10^{-9} m) scale. Metakaolin, when used as a partial replacement for OPC, reacts with $Ca(OH)_2$ to form supplementary calcium-silicate-hydrate which is similar in composition and structure to those obtained from Portland cement. The rate of the pozzolonic reaction is proportional to the amount of surface area available for reaction.

During the present investigation, the influence of Nano-Metakaolin on the compressive strength, split tensile strength and Modulus of Elasticity of cement concrete has been investigated. Also its influence on consistency, initial and final Setting time of cement has been studied. Comparison of cost between normal cement concrete and concrete with cement partially replaced with Nano-Metakaolin has been made.

II. REVIEW OF LITERATURE

Terrence Ramlochana, et al.,(2000) studied the efficiency of high-reactivity metakaolin (HRM) in controlling expansion due to alkali silica reaction (ASR). The expansion of concretes and mortars containing various percentages of HRM as a partial replacement for OPC was studied. The amount of HRM required to limit the expansion to within 0.04% at 2 years was found to be between 10% and 15% depending on the type of aggregate.

G. Batis, et al.,(2005) studied the effect of metakaolin addition on the corrosion resistance of cement mortar. A poor Greek kaolin with low kaolinite content was thermally treated and the produced metakaolin (MK) was ground to the appropriate fineness. It was observed that the addition of metakaolin does not significantly alter the 1-day strength, but it has a very positive effect on the strength after 2 days and specifically at 28 days.

Erhan Guneyisi, et al.,(2007) studied the use of metakaolin (MK) as a supplementary cementing

material to improve the performance of concrete. The results revealed that the inclusion of MK remarkably reduced the drying shrinkage strain, but increased the strength of the concrete in varying magnitudes, depending mainly on the replacement level of MK, w/c ratio, and age of testing. It was also found that the ultrafine MK enhanced substantially the pore structure of the concrete and reduced the content of the harmful large pores, hence made concrete more impervious, especially at a replacement level of 20%.

Morsy M. S., et al.,(2008) investigated the effect of Nano-clay on the mechanical properties and microstructure of Portland cement mortar. The main objective of this research was to constitute a blended cement mortar with high mechanical properties. The Nano-clay used in this investigation was Nano-kaolin. The Nano Metakaolin (NMK) was prepared by thermal activation of kaolin clay for 2 hours at 750^{o}C. The OPC was partially substituted by NMK of 0, 2, 4, 6 and 8% by weight of cement. The results showed that the compressive strength and the tensile strength of the cement mortars with NMK were higher than plain cement mortar with the same w/b ratio. The enhancement in tensile strength was 49%, whereas the enhancement in compressive strength was 7% at 8% NMK.

Dinakar P,(2011) studied the behaviour of metakaolin in concrete composites. He reported that the concrete mixtures produced using High Reactivity Metakaolin (HRMH require less High Range Water Reducer (HRWR) than silica fume mixes to achieve similar workability for the same water to cementitious materials ratio. This reduction in HRWR demand may result in fewer tendencies for surface tearing during finishing operations and could lead to an overall better finish ability. As the replacement level of cement with HRM increases the super plasticiser requirement also increases. The increase was about 0.6% for every 5% increase in metakaolin. The strength of metakaolin concrete may not be same as that of the normal plain cement concrete. Comparing the mixtures containing 5 and 10% HRM and silica fume, it was observed that the compressive and flexural strength in HRM mixtures were significantly greater than those of non-pozzolanic control mixture and slightly higher than the silica fume mixtures.

From the review of literature it is clear that Metakaolin can effectively enhance the properties of cement mortar and concrete. An attempt has been made to understand the effect of addition of nano metakaolin on the mechanical properties of concrete.

III. MATERIALS AND METHODS

A) MATERIALS

1. CEMENT

The cement used during the investigation is 53-grade Ordinary Portland Cement. The cement was purchased from single source. The specific gravity of the above cement was 3.15 and it is conforming to IS: 12269- 1987.

2. AGGREGATES

Natural river sand was used as fine aggregate and broken granite stones of size 20mm complying to IS:383 – 1970 was used as coarse aggregate. Fine aggregates confirm to Zone II grading with specific gravity 2.64 and bulk density of 1560kg/m^3 respectively. The specific gravity of coarse aggregate was 2.83.

3. WATER

Potable water available in laboratory was used in this investigation for making concrete.

4. NANO METAKAOLIN

Metakaolin is a dehydroxylated form of the clay mineral kaolinite. Metakaolin was ground in a high speed ball grinding mill and it was reduced to nano scale. The picture of nano metakaolin taken by Scanning Electron Microscope (SEM) is shown in figure 1.

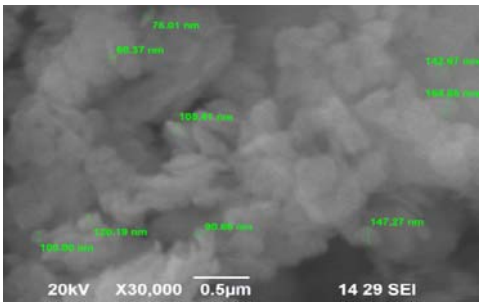

Figure 1: Scanning Electron Microscope Picture of Nano Metakaolin

From figure1 it can be seen that the particle size of nano metakaolin produced in the Ball Grinding mill is around 100 nm.

5. CHEMICAL ADMIXTURES

The chemical admixture used is Conplast SP430 confirming to IS: 9103-1999 and BS: 5075. It is used at higher replacement percentage of cement with Nano-Metakaolin to enhance the workability.

B) METHOD OF PREPARATION OF TEST SPECIMENS

Cylinders with diameter of 150mm and height of 300mm for Split tensile strength and cubes of size 150mm x 150mm x 150mm for Compressive strength were cast. Then the specimens were demoulded and cured in water at a temperature of 20^{0}C prior to

testing. The Tensile strength of the concrete samples was determined at 28th and 56th days as per IS:5816-1999, whereas Compressive strength tests were determined at 28th, 35th and 56th days as per IS: 516-1959.

IV. RESULTS AND DISCUSSION

Various tests have been conducted to find the effect of Nano metakolin on the consistency and setting time of cement. Tests were also conducted to find the influence of nano metakoalin on the properties of different grades of concrete.

1. CONSISTENCY

The variation of consistency of cement paste with addition of nano metakolin is shown in Figure 2.

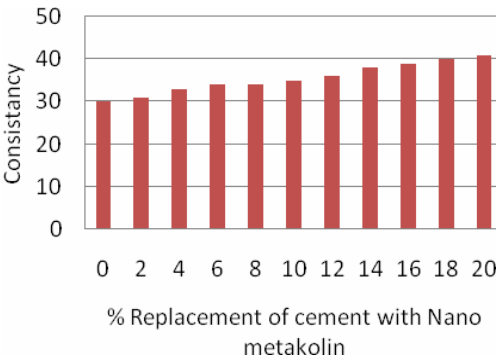

Figure 2: Variation of Consistency with Respect to Percentage Replacement.

From figure 2 it can be seen that the percentage of water required for producing a cement paste of Standard Consistency is increasing with the increase in the amount of Nano-Metakaolin, when used as a partial replacement of cement. The Standard Consistency of normal cement is 30%. The Consistency value increases up to 41% at a replacement percentage of 20. The percentage increase in the Standard Consistency at 20% replacement is found to be 36.6% with respect to the Consistency value of normal cement paste.

2. SETTING TIME

The variations in the initial and final setting times of cement with addition of different percentages of nano metakaolin are shown in figure 3 and figure 4 respectively.

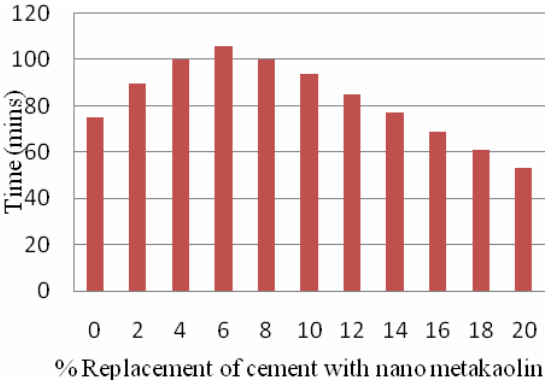

Figure 3: Variation of Initial Setting Time of Cement Paste with Respect to Various Percentages of Nano Metakaolin

From figure 3 it can be seen that the initial setting time of normal cement paste is 75 minutes. The initial setting time was found to increase as the replacement percentage increases up to a replacement percentage of 6%. Beyond 6% replacement, the initial setting time was found to decrease. As per the Indian standards, the initial setting time should not be less than 30 minutes. Here all the replacement percentages satisfy this requirement.

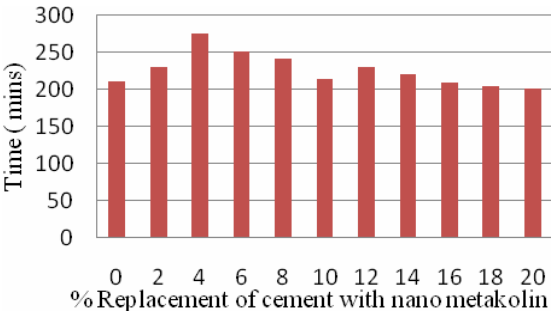

Figure 4: Variation of Final Setting Time of Cement Cement Paste with Respect to Various Percentages of Nano Metakaolin

From figure 4 it can be seen that final setting time of normal cement paste is 210 minutes. The maximum setting time was obtained at 4% replacement of cement with Nano-metakaolin. As per the Indian standards, the final setting time should not be more than 600 minutes. Here all the replacement percentages satisfy this requirement.

3. COMPRESSIVE STRENGTH

The values of compressive strength of reference specimen and the specimens containing various percentages of nano metakaolin are given in Table 1. It is found that compressive strength increases with the increase in the percentage replacement up to a

certain percentage and beyond which it is found to decrease.

TABLE 1 COMPRESSIVE STRENGTH OF DIFFERENT GRADES OF CONCRETE CONTAINING NANO METAKAOLIN

Grade	Test Day	Compressive strength of concrete containing Nano metakaolin in N/mm^2										
		0%	2%	4%	6%	8%	10%	12%	14%	16%	18%	20%
M20	28	29	32	34	36	37	40	38	37	34	32	30
	35	35	33	37	39	40	42	41	40	38	35	32
	56	37	34	40	41	42	43	43	42	40	39	35
M30	28	35	38	41	44	45	48	42	40	36	35	33
	35	38	41	44	46	49	50	46	45	40	36	34
	56	39.5	43	45	48	51	52	49	46	44	42	41
M40	28	45	48	47	48	50	51	47	45	41	39	37
	35	49.5	49	50	51	53	54	50	47	44	41	38
	56	51.5	52	52	54	55	57	55	50	46	44	42
M50	28	51	53	54	55	55	57	55	53	48	46	46
	35	53	53	55	57	59	62	57	53	50	48	46
	56	55	57	58	62	62	65	61	60	55	52	48

From Table 1, it can be seen that there is some improvement in the strength with respect to the age of concrete. The variation in the 28th day, 35th day and 56th day compressive strength of different grades of concrete with various percentages of nano metakaolin are shown in figure 5, figure 6 and figure7 respectively.

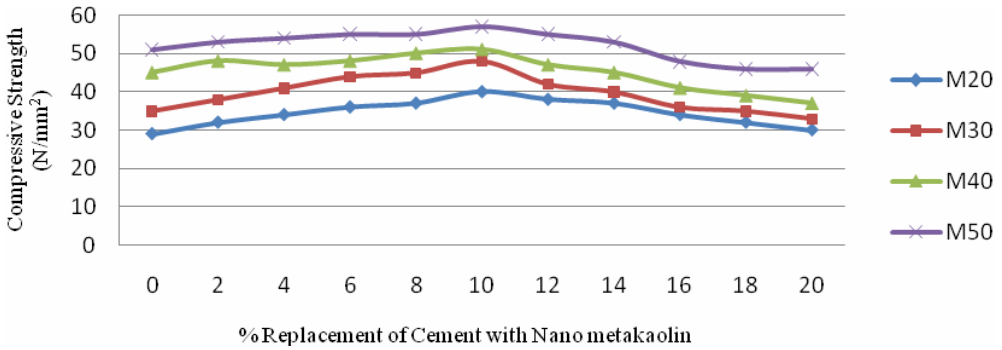

Figure 5: Compressive strength of Concrete at 28th day for Various Replacement percentages of nano Metakaolin.

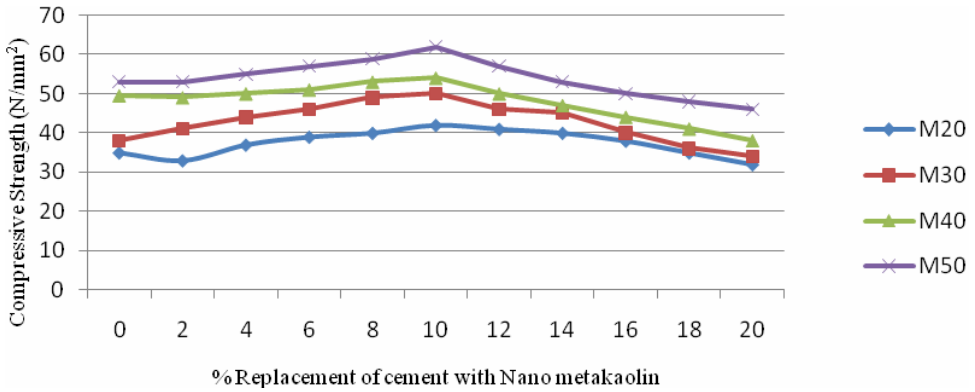

Figure 5: Compressive strength of Concrete at 35th day for

Various Replacement percentages of nano Metakaolin.

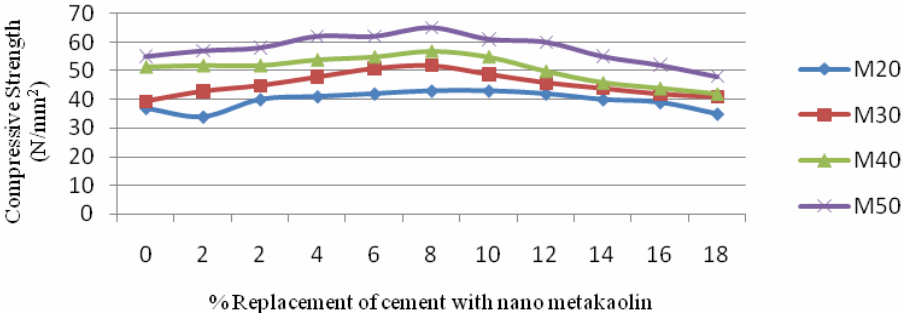

Figure 7: Compressive strength of Concrete at 56th day for Various Replacement percentages of nano Metakaolin.

From figure 5, figure 6 and figure 7, it can be seen that when the replacement percentage is between 10% to 20%, maximum strength is obtained. The increase in the 28th day strength of M20 concrete when the replacement is 10% is around 38%. The increase in the 28th day compressive strength of M50 concrete when the replacement percentage is 10% is around 12%.

4. SPLIT TENSILE STRENGTH

The values of the split tensile strength of the reference specimen and the specimens containing various percentages of nano metakaolin are given in Table 2. It is found that split tensile strength also increases with the increase in the percentage replacement up to a certain percentage and then it is found to decrease.

TABLE 2 SPLIT TENSILE STRENGTH OF DIFFERENT GRADES OF CONCRETE CONTAINING NANO METAKAOLIN

Grade	Test Day	Split tensile strength of concrete containing Nano metakaolin in N/mm²										
		0%	2%	4%	6%	8%	10%	12%	14%	16%	18%	20%
M20	28	2.63	2.77	3.19	3.19	3.26	3.33	3.36	3.26	3.2	3.1	2.19
	56	2.84	3.05	3.26	3.54	3.61	3.81	3.85	3.61	3.4	3.19	3.09
M30	28	3.19	3.26	3.19	3.12	3.33	3.46	3.51	3.19	3.05	3.05	2.91
	56	3.21	3.28	3.47	3.19	3.47	3.53	3.61	3.33	3.25	3.25	3.05
M40	28	3.26	3.32	3.56	3.89	4.2	4.38	4.26	3.82	3.74	3.68	3.25
	56	3.33	3.61	3.61	3.95	4.3	4.44	4.30	3.88	3.78	3.72	3.26
M50	28	3.46	3.54	3.43	3.47	4.13	3.82	3.63	3.47	3.75	3.63	3.47
	56	3.54	3.61	4.02	4.3	4.44	4.23	4.09	3.74	3.88	3.74	3.54

From Table 2, it can be seen that the maximum split tensile strength occurs between 8 to 12% replacement of cement with nano metakaolin for different grades of concrete.

The variations in the split tensile strength of different grades of concrete with various percentages of nano metakaolin on 28th and 56th day are shown in figure 8 and figure 9 respectively.

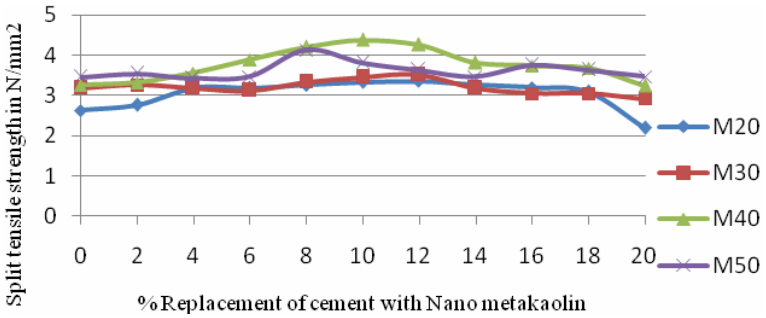

Figure 8: Split Tensile Strength of Concrete at 28th day for Various Replacement percentages of nano Metakaolin.

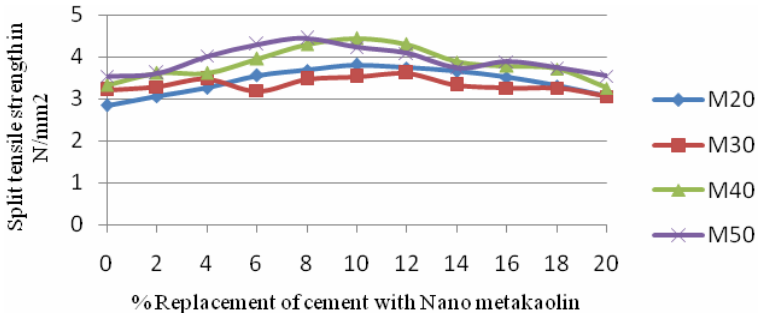

Figure 9: Split Tensile Strength of Concrete at 56th day for Various Replacement percentages of nano Metakaolin.

From figure 8 and figure 9, it can be seen that the optimal replacement percentage of cement with metakaolin is between 8 to 12%. The increase in the 28th day split tensile strength of M20 concrete with respect to normal concrete is around 28% when the replacement percentage is 12%. For M50 concrete, the increase in the 28 day split tensile strength is around 19% when the replacement percentage is 8%.

5. MODULUS OF ELASTICITY

The value of modulus of elasticity of the reference specimen and the specimens containing various percentages of nano metakaolin are given in Table 3.

From Table 3, it can be seen that modulus of elasticity values increase with the increase in the percentage replacement up to a certain percentage further which it was found to decrease. The variations in the modulus of elasticity of different grades of concrete with various percentages of nano metakaolin on 28th and 56th day are shown in figure 10 and figure11 respectively.

TABLE 3 MODULUS OF ELASTICITY OF CONCRETE CONTAINING NANO METAKAOLIN

Grade	Test Day	*Modulus of elasticity of concrete containing Nano metakaolin (x 10^4) in N/mm^2*										
		0%	*2%*	*4%*	*6%*	*8%*	*10%*	*12%*	*14%*	*16%*	*18%*	*20%*
M20	28	2.71	2.86	3.05	3.52	3.66	3.8	3.75	3.43	3.21	3.03	2.82
	56	3.15	3.22	3.45	3.54	3.76	3.86	4.09	3.82	3.56	3.25	2.98
M30	28	2.86	3.02	2.98	3.36	3.69	3.9	3.5	3.3	3.56	2.94	2.96
	56	3.20	3.52	3.76	3.65	3.89	4.11	4.05	3.86	3.75	3.33	3.21
M40	28	3.15	3.2	3.55	3.45	3.83	4.12	4.01	3.89	3.45	3.20	3.12
	56	3.8	3.86	3.60	3.9	4.18	4.2	4.16	4.12	3.54	3.38	3.26
M50	28	3.35	3.56	3.72	3.45	4.28	4.32	4.25	4.33	4.19	3.89	3.15
	56	3.95	3.65	4.27	4.3	4.59	4.6	4.45	4.39	4.2	3.99	3.33

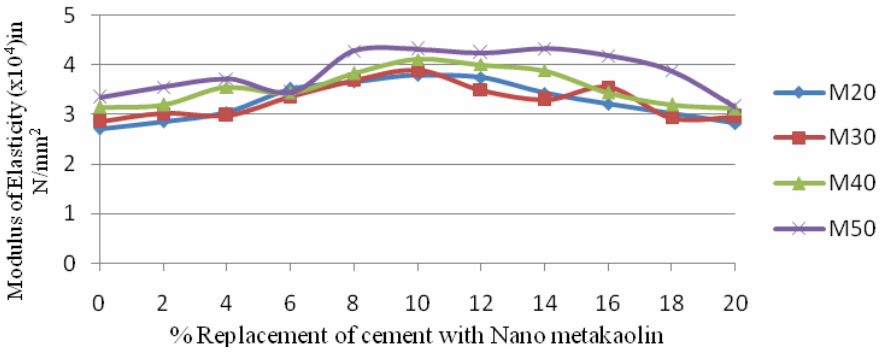

Figure 10: Modulus of Elasticity of Concrete at 28th day for Various Replacement percentages of nano Metakaolin.

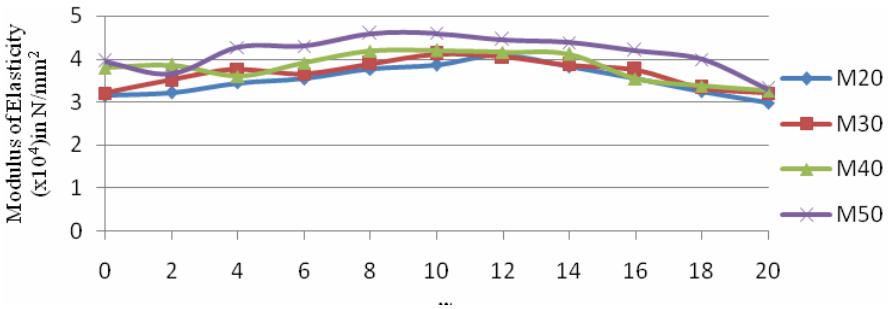

Figure 11: Modulus of Elasticity of Concrete at 56th day for Various Replacement percentages of nano Metakaolin.

From figure 10 and figure 11, it can be seen that the modulus of Elasticity is maximum when the replacement percentage is 10%.

V COST COMPARISON

Figure 12 shows the cost comparison between normal concrete and concrete containing Nano-Metakaolin at various percentages. The cost of $1m^3$ of normal concrete for M20, M30, M40 and M50 grade were found to be Rs 2821/-, Rs 3328/-, Rs 4194/- and Rs 4777/- respectively using the rates prevailing at the research location. The cost of concrete with 10% replacement, which gave the maximum compressive strength were found to be Rs 3144/-, Rs 3731/-, Rs 4733/- and Rs 5409/- for M20, M30, M40 and M50 respectively. The increase in the cost at 10% replacement is found to be 11%, 12%, 13% and 13% for M20, M30, M40 and M50 respectively. The increase in the cost of concrete containing nano metakaolin is marginal when compared with the in the strength.

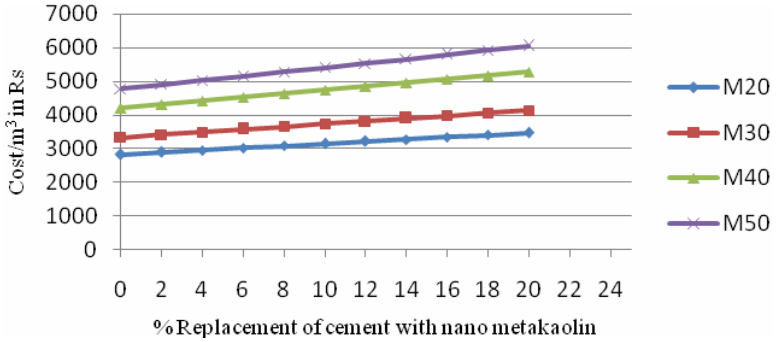

Figure 12: Comparison of Cost of 1 m^3 of Concrete in Rs

CONCLUSIONS

- It is found that partial replacement of cement with Nano-Metakaolin has a greater influence on the strength parameters of concrete.
- The optimum percentage at which cement can be replaced with Nano-Metakaolin is 10%.
- The increase of Compressive strength varies between 5-38% for M20 grade, 2-37% for M30 grade, 3-13% for M40 grade and 3-18% for M50 grade of concrete.
- The increase of Split Tensile strength varies between 5-36% for M20 grade, 2-13% for M30 grade, 2-34% for M40 grade and 2-26% for M50 grade of concrete.
- The increase in cost for 10% replacement varies between 11-13% for all grades of concrete. This increase is marginal compared to the improvement in strength. Hence Nano-Metakaolin may be adopted as an effective pozzolanic material to partially replace cement in concrete.

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