STRENGTH CHARACTERISTICS OF SOIL TREATED WITH NANO ZINC OXIDE FOR PAVEMENT APPLICATIONS

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ABSTRACT

Soil improvement is a challenging job and needs to be exercised before taking up any important infrastructural project. An attempt to stabilize the soil by nano zinc oxide was made in this research to showcase the potentialities of the nano technology. Silty sand was mixed with nano zinc oxide by 1%, 1.5% and 2% by dry weight of soil. Further to check the effect on strength, Ordinary Portland cement was added by 2%, 4% and 6% to each proportion by dry weight of soil. The unconfined compressive strength was observed to be increased by 43.5 times on adding 1.5% of nano zinc oxide to the soil. Further on adding cement by 2%, 4% and 6% the unconfined compressive strengths were observed to be enhanced by 45.1%, 107.09% and 147.5% respectively when compared to neat soil. The soil treated with nano zinc oxide and cement satisfies the 7 days unconfined compressive strength criteria for sub base layers in the design of flexible pavements pertaining to the Indian sub continent. This research is thus an attempt to stabilize the soil by adopting the nano technological approach and offer a re-engineered solution for the pavement engineering practices.

KEYWORDS

Silty sand, nano zinc oxide, cement, unconfined compressive strength

1. INTRODUCTION

Soil improvement is a rigorous task in any infrastructural application so as to provide a sound foundation to any structure. The soils if weak and expansive may pose lot of problems like swelling, shrinkage etc. and which may reduce the future life of the structure if not properly treated. Therefore proper treatment of soils is very essential thus ensuring a strong base before the construction.

Many techniques of soil improvements like soil with fly ash, soil reinforced with natural and synthetic fibers, soil reinforced with pozzolana, lime and cement, etc. have been implemented by several researchers in the past. There are numerous examples and researches which reveal the use of such conventional materials mentioned above in the past three to four decades. Apart from this, there is one such unconventional technology which emphasizes on controlling the things over a micro scale that can altogether bring a great change in re-engineering the constructional processes catering to various applications in the field. Nano technology is now an upcoming field and has gained a good momentum over the past decade showcasing the potentialities of these very promising materials. Almost every field of science and engineering emboldens the importance of this technology that caters to the need of the hour thus conforming the industry standards.

The study aims at improving silty sand by adopting nano zinc oxide powder and optimizing its proportions in suitable combinations with cement to unveil the geotechnical improvements pertaining to unconfined compressive strength parameters which will cater the needs of good subgrade/subbase material for flexible pavements.

2. BACKGROUND RESEARCH

Many earlier researchers have assessed the suitability of fly ash in various applications since past two decades. Improvement in bearing capacities of soils has been reported by adopting pulp mill fly ash and lime as in [1]-[2]. Studies on use of class ‘F’ fly ash with soil-cement and soil-lime for base layers in highways have been presented as in [3]. The improvements in geotechnical properties of expansive soils adopting varying percentages of fly ash have been presented as in [4]. Saturated drained triaxial tests were performed to analyze the improvement in soils with addition of fly ash and calcium chloride considering the curing conditions as in [5]. Use of polyester fiber inclusions with fly ash and cement additive combinations was investigated to study effect of ductility to the soil mixes [6]-[7]. On site case studies on fly ash stabilized soils also have been put up to measure the increase in strength and stiffness of fine subgrade by measuring the CBR and resilient modulus properties [8]. The improvements in strength, CBR and plasticity characteristics of soft soil have been reported by adopting sewage sludge ash with lime as in [9].

The importance of nano technology gained momentum in the last decade and thereafter few researchers have tried to explain the versatility of these very novel materials in various streams of science and engineering. Nano-silica was utilised in increasing the pozzolanic activities of the high volume fly ash high strength concrete as reported in [10]. Unconfined compressive strength properties of sewage sludge ash were improved by adding nano silica and nano alumina additives to soft soils in small proportions [11]-[13]. The physical, mechanical and thermal properties of concrete were improved by addition of nano zinc oxide as in [14]-[15]. Studies on improvement in CBR values and plasticity properties on Nigerian soils by treating them with organo silane nano material have been presented as in [16]. Effect of adding class ‘F’ fly ash and organo silane nano material on CBR and plasticity properties of soft marine clays have been reported in [17]. Improvement in strength characteristics of silty sand samples by adding colloidal nano silica have been discussed as in [18].

Earlier researches showcase the applications of nano materials in almost all fields of science and engineering. Lot of work has been done related to civil engineering concrete sector. However, very less work reveals the usage of nano materials related to geotechnical and pavement engineering applications and therefore there seem to be enough opportunities in this field ahead to study the impact of nano materials on soils. This research is thus an attempt to stabilize the soil by adopting the nano technological approach and offer a re-engineered solution for the pavement engineering practices.

3. CHARACTERIZATION OF MATERIALS

3.1 Soil

Powai soil (termed as ‘PS’ hereafter) was collected from the premises of IIT, Bombay. Table 1 below represents the physical properties of soil.

TABLE 1 Physical properties of Soil

Properties	Soil
Specific gravity [19]	2.63
Maximum dry density (gm/cm^3)	1.72
Optimum moisture content (OMC)%	19
Gravel (%)	19
Sand (%)	35.9
Silt (%)	32.8
Clay (%)	12.3
Liquid Limit (%)	45.4
Plastic limit (%)	30.73
Shrinkage limit (%)	16.23
Plasticity Index (%)	14.67
Group symbol [20]	SM
Coefficient of permeability ‘k’ (cm/sec)	$3.457x\ 10^{-5}$
Unsoaked CBR (%)	33.36
Soaked CBR (%)	14.07

3.2 Nano zinc oxide

Nano zinc oxide (ZnO) metallic oxide powder synthesized in the Mettallurgy and Material Science department of IIT, Bombay was obtained for the study.

Table 2 represents the physical properties of nano ZnO.

TABLE 2 Physical properties of nano ZnO

Property	value
Average Particle size Specific surface area Purity Density	35 nm 14.26 m^2/g 99.9% 5.6 gm/cm^3

Figure 1 below represents the Scanning Electron Microscopic image of nano ZnO.

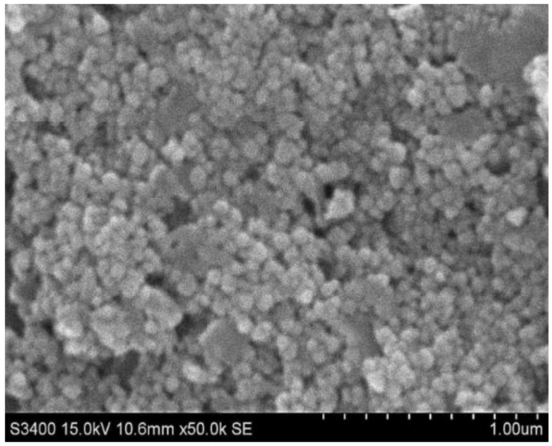

FIGURE 1 SEM image of nano ZnO

3.3 Ordinary Portland Cement

Ordinary Portland cement (OPC) of 53 grade used in the study was obtained from the Structural Evalutaion and Material Testing Laboratory of IIT, Bombay.

Table 3 represents the physical properties of OPC (53 Grade)

TABLE 3 Physical properties of OPC

Property	value
Specific surface area	2365 cm^2/g
Soundness	5mm
Initial setting time	36 minutes
Final setting time	500 minutes
Compressive Strength (7 days)	395 Mpa

4. SAMPLE PREPARATION AND METHODOLOGY

4.1 Test methodology: Modified proctor compaction test

Nano zinc oxide (ZnO) was mixed with the oven dried soil in increasing proportions by 1%, 1.5% and 2% of dry weight of soil. Later, Ordinary Portland cement (OPC-53 grade) was mixed with every proportion by 2%, 4% and 6% dry weight of soil Modified proctor compaction tests (simulating the heavy compaction in field) were initially performed to compute the modified proctor densities for all the samples. The modified proctor compaction tests were performed with the help of a miniature CBR mould fabricated on the similar lines of proposed mini compaction apparatus [22]. Fig. 2 represents the miniature CBR apparatus used in the study.

FIGURE 2 Miniature CBR apparatus [22]

4.2 Test methodology: Unconfined Compressive strength test

Soil samples were prepared in the same manner as per the procedure mentioned in 4.1. (38mm x 76mm) samples were prepared for conducting the unconfined compressive strength tests thus by observing 'L/D' ratio of '2'. The samples were cured in a dessicator for 7, 14 and 28 days. The tests were conducted in accordance with [22]. Fig 3 represents the curing of samples in dessicator.

FIGURE 3 Curing of samples in dessicator

5. RESULTS AND DISCUSSIONS

5.1 Modified proctor compaction tests

Table 4 below represents the modified proctor compaction test results.

TABLE 4 Modified compaction test results

Sample details	MDD (gm/cm^3)	OMC (%)
PS (neat soil)	1.72	19.0
PS + 1% nano ZnO	1.715	17.2
PS + 1% nano ZnO + 2% cement	1.72	17.4
PS + 1% nano ZnO +4% cement	1.74	17.5
PS + 1% nano ZnO + 6% cement	1.75	17.7
PS + 1.5 % nano ZnO	1.72	17.4
PS + 1.5 % nano ZnO + 2% cement	1.73	18.1
PS + 1.5 % nano ZnO + 4% cement	1.75	18.7
PS + 1.5 % nano ZnO + 6% cement	1.76	19.1
PS + 2 % nano ZnO	1.73	17.5
PS + 2 % nano ZnO + 2% cement	1.74	18.2
PS + 2 % nano ZnO + 4% cement	1.75	18.4
PS + 2 % nano ZnO + 6% cement	1.77	18.6

From the above results of modified proctor tests it can be seen that the dry density of the soil slightly increases on account of addition of nano material and cement. When cement is mixed along with nano material the cementation starts in the soil on account of hydration. It is observed that optimum moisture contents go on increasing with the increase in cement content as it requires more water for mixing on account of heat of hydration.

5.2 Unconfined Compressive strength

Figures 4 to 12 represent the strain strain curves for UCS values for soil mixed with 1%, 1.5% and 2% nano zinc oxide with varying cement contents for 7, 14 and 28 days of curing.

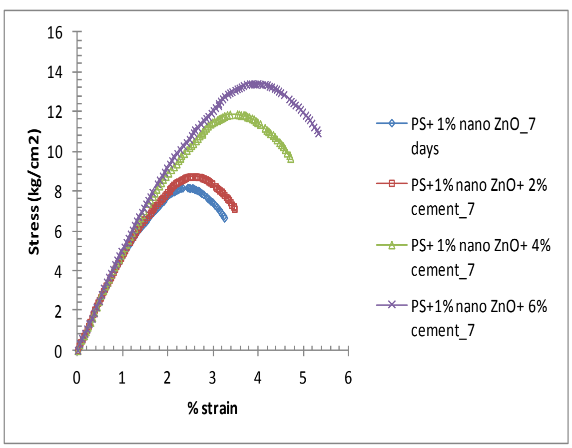

FIGURE 4 Stress strain curves of soil mixed with 1% nano zinc oxide and varying percentages of cement for 7 days of curing

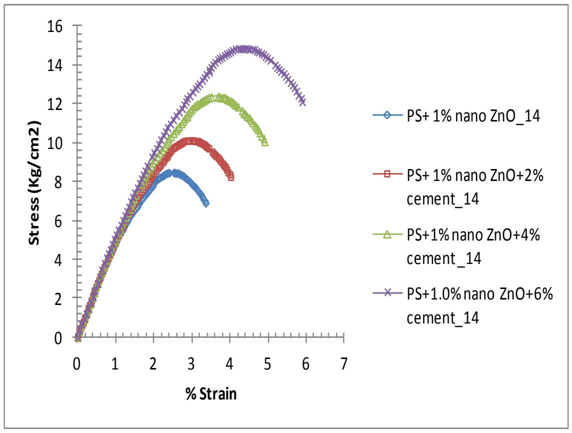

FIGURE 5 Stress strain curves of soil mixed with 1% nano zinc oxide and varying percentages of cement for 14 days of curing

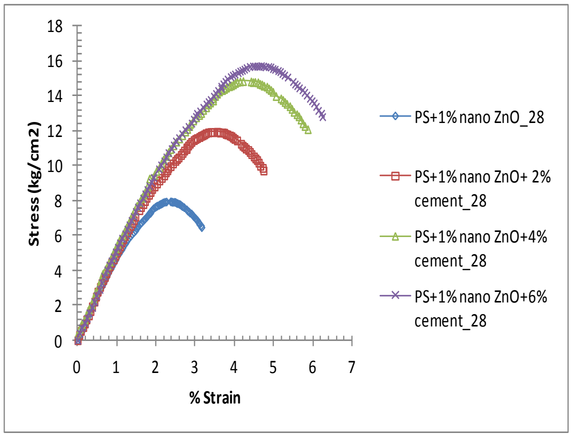

FIGURE 6 Stress strain curves of soil mixed with 1% nano zinc oxide and varying percentages of cement for 28 days of curing

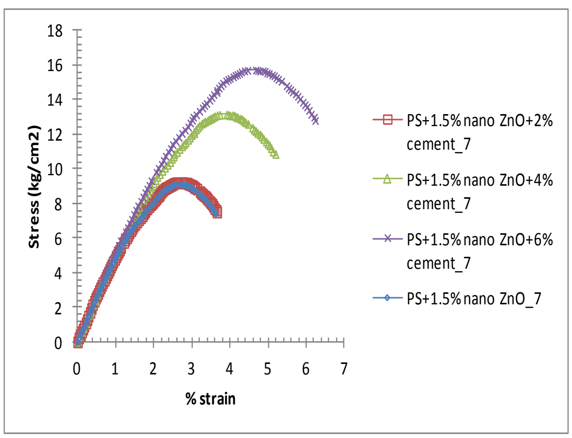

FIGURE 7 Stress strain curves of soil mixed with 1.5% nano zinc oxide and varying percentages of cement for7 days of curing

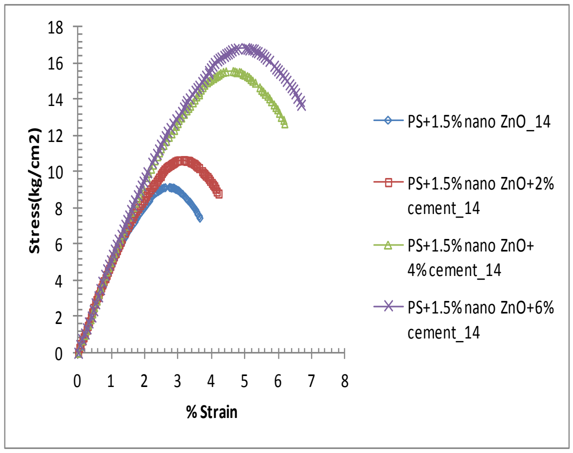

FIGURE 8 Stress strain curves of soil mixed with 1.5% nano zinc oxide and varying percentages of cement for 14 days of curing

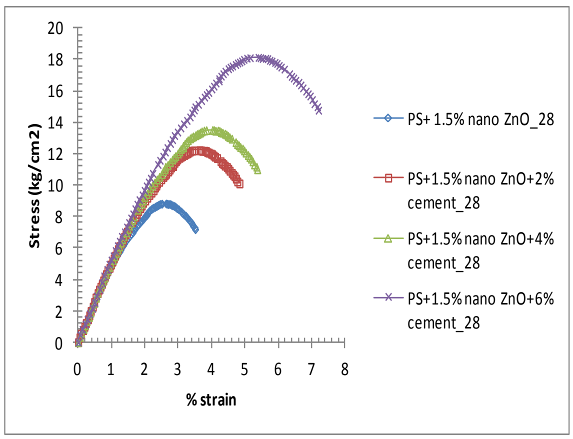

FIGURE 9 Stress strain curves of soil mixed with 1.5% nano zinc oxide and varying percentages of cement for 28 days of curing

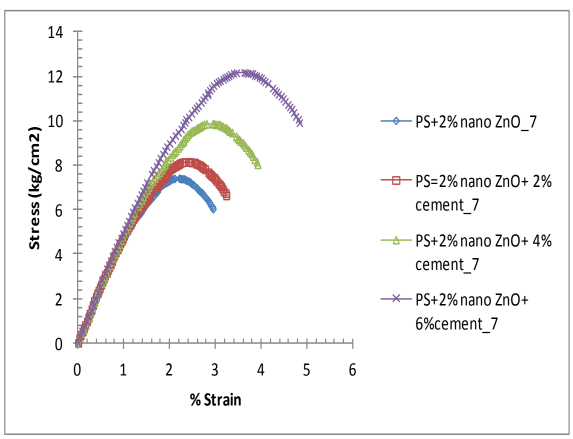

FIGURE 10 Stress strain curves of soil mixed with 2% nano zinc oxide and varying percentages of cement for 7 days of curing

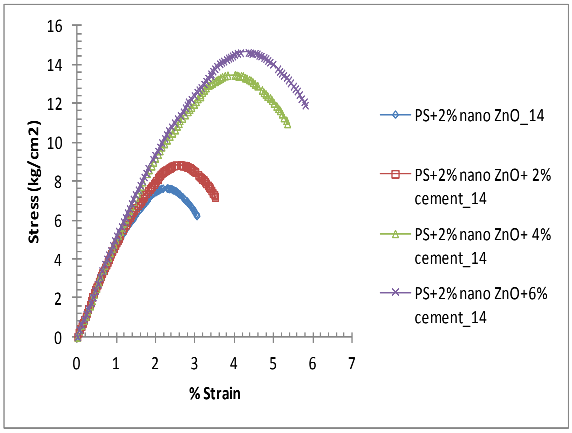

FIGURE 11 Stress strain curves of soil mixed with 2% nano zinc oxide and varying percentages of cement for 14 days of curing

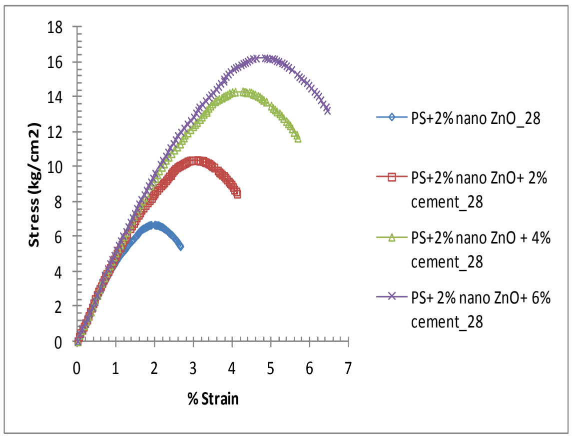

FIGURE 12 Stress strain curves of soil mixed with 2% nano zinc oxide and varying percentages of cement for 28 days of curing

From the above results it is observed that as the dose of nano zinc oxide is increased in the soil the strength goes on increasing. The 7 days strength is seen to be increased by 43.5% as compared to the neat soil on addition of 1.5% of nano zinc oxide. Further beyond 1.5% the strength was observed to be decreased. The strength at 14 days was not significantly improved whereas the 28 days strength was observed to be slightly lowered than that of the 7 days strength. For soil with 1.5% of nano ZnO the 28 days strength was observed to be reduced by 3% than that of 7 days.

There was a fungus formation observed on the 28 days specimens of soil added with nano zinc oxide. It can be interpreted that since zinc is a heavy metal the chemical reaction between soil and nano zinc oxide in presence of moisture promotes the decay of organic matter in the soil with formation of algae and fungus on the specimen. This can be attributed to the decrease in 28 days strength to a certain extent.

Further on addition of cement to soil and nano zinc oxide the strength was observed to be considerably improved for all nano zinc proportions. With the addition of 4% and 6% cement to the soil with 1.5% nano ZnO the 7 days strength was observed to be increased by 44.2% and 72.4% respectively. It was also observed that the specimens reinforced with cement failed at slightly higher strains than those with only nano ZnO. The strengths were further observed to be increased for 14 and 28 days of curing on account of addition of 2%, 4% and 6% of cement to all the nano ZnO proportions. Thus when compared to the neat soil the 7 days strengths for soil with 1.5% of nano ZnO with 2%, 4% and 6% cement were observed to be increased by 45.1%, 107.09% and 147.5% respectively. There was no formation of fungus observed on any specimens mixed with cement and nano ZnO. Thus it was observed that 1.5% of nano zinc oxide yielded optimum results in all the variations considered in the tests. Table 5 summarizes the UCS results of soil treated with 1%, 1.5% and 2.0% of nano ZnO with varying cement proportions for 7, 14 and 28 days of curing.

TABLE 5 Unconfined Compressive strength results of soil with 1%, 1.5% and 2.0% nano ZnO with 2% , 4% and 6% cement for 7, 14 and 28 days of curing

Sample details	UCS for 7 days of curing (Kg/cm^2)	UCS for 14 days of curing (Kg/cm^2)	UCS for 28 days of curing (Kg/cm^2)
PS	6.345	6.221	5.65
PS + 1% nano ZnO	8.182	8.464	7.956
PS+1% nano ZnO+2% cement	8.745	10.12	11.945
PS+1% nano ZnO+4% cement	11.874	12.36	14.851
PS+1% nano ZnO+6% cement	13.415	14.851	15.732
PS + 1.5% nano ZnO	9.11	9.162	8.832
PS+1.5% nano ZnO+2% cement	9.212	10.647	12.23
PS+ 1.5% nano ZnO+4% cement	13.14	15.572	17.215
PS+ 1.5% nano ZnO+6% cement	15.71	16.832	18.14
PS+ 2% nano ZnO	7.415	7.652	6.676
PS+ 2% nano ZnO+2% cement	8.153	8.834	10.38
PS+ 2% nano ZnO+4% cement	9.876	13.472	14.321
PS+ 2% nano ZnO+6% cement	12.176	14.625	16.245

The strength could be attributed to the formation of zinc hydroxide and calcium silicates formed in presence of water with the soil. Since the silica from the soil reacts with the calcium it forms C-S-H gel thus imparting strength to the soil thereby increasing the strength with the age of curing.

5.3 Suitability as a good subbase material

It is observed that the soil when mixed with 1%, and 1.5% of nano zinc oxide it just satisfies the UCS criteria for chemically stabilized soil for sub base courses for 7 days of curing as per IRC:37-2012 [23] Further on adding 2% and 4% cement the UCS criteria are well satisfied within the specified range mentioned in the above code. It is thus observed that soil with 1.5%

nano ZnO with 4% cement well satisfies the 7 days UCS criteria as per IRC:37-2012 for the design of flexible pavements pertaining to the Indian sub continent as in [23].

CONCLUSIONS

An experimental study was conducted on silty sand type of soil by reinforcing with nano zinc oxide and cement to assess the performance of strength characteristics to check its suitability for the design of flexible pavements. Following were the major conclusions drawn from the study.

1. The unconfined compressive strength of soil was observed to increase with increase in nano zinc oxide proportions. Addition of 1.5% of nano ZnO yielded optimum results.

2. On addition of 2%, 4% and 6% cement to soil with 1.5% nano ZnO the 7 days unconfined compressive strengths were observed to be enhanced by 45.1%, 107.09% and 147.5% respectively when compared to neat soil.

3. The soil samples treated with varying proportions of cement were observed to yield a higher strength and failed at slightly higher strains as compared to samples treated with only nano zinc oxide.

3. Soil mixed with 1.5% nano ZnO with 4% cement well satisfies the 7 days UCS criteria for chemically stabilized soil for sub bases as per ‘IRC:37-2012 – Tentative Guidelines for the design of flexible pavements’ pertaining to the Indian sub continent

ABBREVIATIONS USED

The following symbols are used in this paper.

UCS = Unconfined Compressive strength

PS = Powai soil

ZnO = Zinc oxide

MDD = Maximum dry density

OMC = Optimum moisture content

OPC = Ordinary Portland cement

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