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Research Article

Performance of multiwalled carbon nanotube doped fly ash based clay bricks

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Abstract
The major goal of this research is to propose an energy-efficient process to produce economical bricks in a very short amount of time. These bricks were prepared by baking cylindrical clay specimens in a muffle furnace at 900 degrees Celsius for 6 hours. The clay specimens were reinforced with fly ash and multiwalled carbon nanotubes (MWCNT). The influence of MWCNT in various proportions such as 0.1 %, 0.01 %, 0.001% of water by weight, was observed with a high clay replacement ratio (10 %, 20%, 30%, 40%, 50%) on various properties of bricks. Soil, fly ash, and MWCNT used in the study were characterized using microscopic techniques such as x-ray diffraction (XRD) analysis and scanning electron microscopy-energy dispersive spectroscopy (SEM-EDS). The findings demonstrate that adding up to 50% (by weight) fly ash along with MWCNT (0.1 %, 0.01 %, 0.001% of water by weight) to normal cylindrical clay bricks can improve their characteristics when baked at 900 degrees Celsius for 6 hours in a muffle furnace. The combination of clay, fly ash, and MWCNT performed remarkably well in laboratory testing due to its efficient void filling capacity and pozzolanic nature. These bricks have a higher compressive strength, less water absorbent, are structurally homogeneous, sound, and less harmful to the environment. The effective use of fly ash addition is not only beneficial to the protection of natural clay resources, but it is also a viable option for challenging and expensive waste disposal issues.

Keywords
Clay bricks, MWCNT, Fly ash, Muffle furnace, SEM-EDS, XRD.

1.Introduction
Brick has been one of the most widely used building materials all over the world. The global annual production of bricks amounts to 1500 billion units and a majority of which is manufactured in Asia [1]. *Figure 1* and *Figure 2* depicts the distribution of global brick production among different countries. The high production of clay-based bricks can be attributed to its wide acceptance among the producers as well as the consumers. The use of earth-based raw resources such as clay, shale, sand, etc. in traditional clay-based brick manufacture leads to an accelerated drain of resources along with severe environmental damages. The rampant excavation of top soil in the production of traditional bricks has severe environmental concerns [2]. In addition to the unsustainable use of natural resources, emissions from brick kilns spread across the globe are a major cause of air pollution.

Around 100,000 large-scale kilns with permanent chimneys are in operation, including around 1,900 in India and 6,000 in Bangladesh. Latin American countries are also home to a large number of bricks manufacturing plants, including 17,000 in Mexico, 6,898 in Brazil, 2,453 in Colombia, 2,222 in Peru, and 300 in Chile [3]. India alone uses roughly 31 million metric tonnes of coal each year [4]. Brick manufacture, despite being a small and minor industry, may produce substantial volumes of particle and gaseous air pollution, especially when basic combustion techniques are utilized. In South Asia, conventional small-scale brick kilns are ubiquitous, and they are associated with impaired combustion technology and little to no pollution management [5], leading to increased carbonaceous emissions. Black carbon emissions from brick kilns in India have been estimated to be in the hundreds of thousands of metric tonnes per year [4], accounting for more than 80% of total black carbon emissions from brick kilns in South Asia [6].

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The declining availability of natural raw materials like clay, sand, shale etc. and emissions coming from kilns encourages to explore for alternate techniques to prepare bricks in an eco-friendly manner. Environmental concerns are compelling the builders to adopt more environmentally friendly methods in order to conserve naturally available resources. The new construction material should be widely acceptable, economically feasible, environmentally benign, and preferably made from industrial waste. Several studies have been conducted incorporating different industrial waste materials like haematite tailings [7], fly ash [8−12], granite sawing wastes [13], municipal solid waste incinerator slag [14], gold mill tailings [15], granite-basalt fine quarry residue, granulated blast furnace slag, kaolin fine quarry residue [16], paper production residues [17], cigarette butts [18], rice husk ash [19] etc.

In developing nations like India, the increased usage of thermal power plants for energy generation produces a large amount of toxic fly ash, which pollutes the environment and is expensive to store. *Figure 3* depicts the generation and utilization trends of fly ash in India from 2009-2020. The substantial difference between its production and utilization provides an opportunity for the researchers to think of new areas of application. Fly ash contains pozzolanic properties and can be used in the manufacture of bricks as a reinforcing agent [2].

Nanomaterials like nano silica, nano lime etc. [20−26] have been used to improve the properties of soil with which bricks are manufactured. Carbon-based nanomaterials, especially multiwalled carbon nanotubes (MWCNT) and carbon nanofibers (CNF), have remarkable material properties such as high tensile strength, hardness, elastic modulus, and electrical properties [25]. The influence of MWCNT on various properties of bricks is still under study and some encouraging results have been obtained.

The current challenges like safe disposal of fly ash, increasing demand for good quality clay bricks, and environmental pollution has forced the researchers to think of an alternative that is energy-efficient, reasonably priced, and uses waste material in appreciable quantity.

The objective of the current study was to study the mineralogical, chemical, and morphological characteristics of the materials like soil, fly ash, and MWCNT. The study of these characteristics is important because it gives basic information about these materials. This information can further help researchers to understand the utilization of these materials in brick production. The study was focused to understand the effect of utilization of MWCNTs with fly ash as a reinforcement in various proportions in the production of muffle-baked clay bricks. The study provides a faster energy-efficient method to produce good-quality clay bricks.

A comprehensive literature review on the usage of waste materials followed by a generous characterization of different materials and methodology used in the study is presented in the upcoming sections of the paper. A section presenting the results and its relevant discussions is also included in the paper. Separate sections are dedicated for highlighting the limitations of the current study along with conclusions and future scope of work.

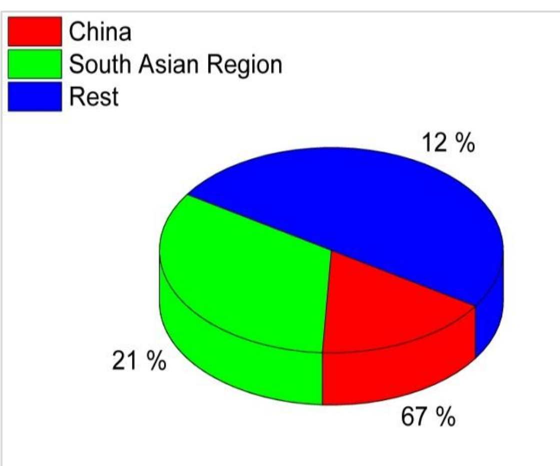

Figure 1 Production of Bricks (Globally)

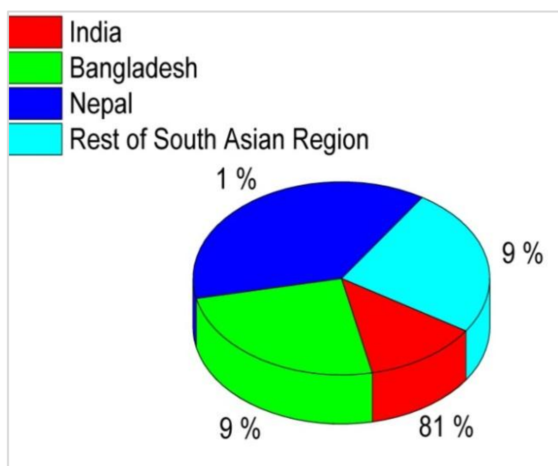

Figure 2 Production of Bricks in South Asian Region

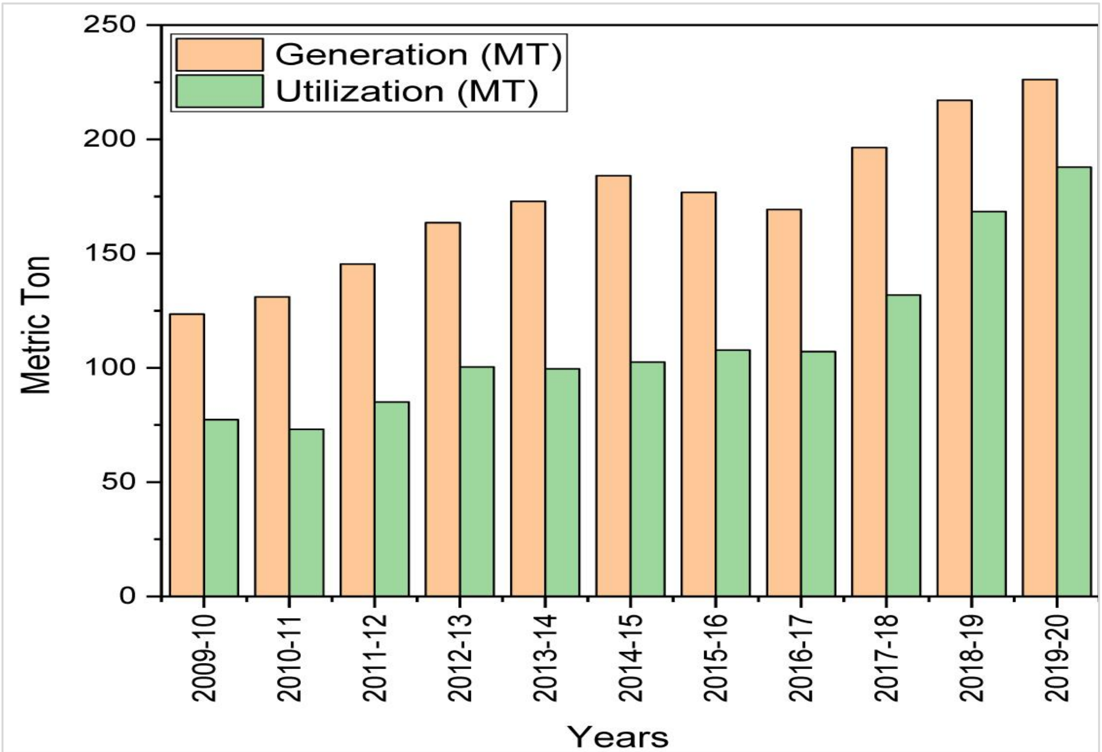

Figure 3 Generation and utilization of Fly Ash in India (Metric Ton)

A comprehensive literature review on the usage of waste materials followed by a generous characterization of different materials and methodology used in the study is presented in the upcoming sections of the paper. A section presenting the results and its relevant discussions is also included in the paper. Separate sections are dedicated for highlighting the limitations of the current study along with conclusions and future scope of work.

2.Literature review

After the initial screening and identification of waste material (fly ash) and nanomaterial (MWCNT), the authors have comprehensively examined different methodologies adopted in brick production. The suitability of various waste materials as an effective replacement for conventional materials in brick production is very important and needs to be studied. The drying and firing of bricks is a crucial part of the brick production process. A detailed description of various studies highlighting the drying and firing conditions in the presence of different waste materials is presented in *Table1*.

It can be seen in *Table 1* that different drying conditions and firing conditions have been used by various researchers. In the line with the same trend, the authors have chosen to use 24 hours of sun drying followed by 24 hours of oven drying at 105 degrees Celsius. The bricks were then baked for 6 hours in a muffle furnace at 900 degrees Celsius.

Table 1 Studies incorporating waste materials in brick production

Material	**Drying condition**	**Firing condition**	**Citation**
Class F fly ash and hematite tailings	6–8 hours of drying in a 105°C oven	2 hours in an electric furnace at 6 degrees Celsius/ minute till 850–1050 degrees Celsius	[7]
Fly ash	2 days at room temperature, 4 hours at 60 °C, and 6 hours at 100 °C	100°C/h at a temperature less than 500°C, 50°C/h for 500°C to 1000, 1050, or 1100°C, and at the maximum temperature for 8 hours in an electric furnace	[8]
	2 days of air drying	For 24 hours, they were fired in a laboratory-grade furnace at 850 °C and 1000 °C, respectively.	[9]
	An industrial clay brick plant's	An industrial clay brick plant's procedure is	[10],

Material	Drying condition	Firing condition	Citation
	procedure is followed.	followed.	[11]
	3 days of drying	1000–1300 °C	[12]
Granite sawing wastes	3 days of drying	Temperatures ranged from 750 to 1200 °C throughout the firing process.	[13]
Municipal solid waste incinerator slag	24 hours of air-drying at room temperature followed by oven-drying for 24 hours at 80°C.	6 hours at 800, 900, or 1000 °C	[14]
Gold mill tailings	2 days at room temperature, 3 days in the sun	9 hours in an electric furnace at 750, 850, or 950 degrees Celsius	[15]
Cigarette butts	For 24 hours, it was dried at 105°C.	1050°C fired in a furnace.	[18]
Rice husk ash	8 days in the sun at 30°C, then 24 hours in an oven at 105°C	Continuously fired in a furnace at 250, 500, and 750 °C for 2 hours each, then at 1000 °C for 2, 4, or 6 hours	[19]
Waste glass powder	7 days of air drying	800 °C to 1000°C for 20 days in Hoffman kiln	[27]
Olive mill waste	12 hours at 40°C followed by 110°C for 24 h	600°C at 2.5°C/ min and then heating at 10°C/ min up to 850, 950 and 1050°C for 2 h	[28]
Bottom Ash	Air drying at room temperature for 72 hours followed by 55-65 °C for 24 h and then at 100-110 °C for 24	Firing at 1000°C for 1 hour.	[29]
Petroleum effluent treatment plant sludge	Room temperature	1000–1100 °C in bull trench brick kiln.	[30]
Marble waste	8 days of air drying under shelter	912 °C in a brick kiln	[31]
Contaminated peanut with aflatoxins	50 °C for 24 h, followed by drying at 80 °C for 3 h, and finally drying at 110 °C for 3 h	Fired with a heating rate of 10 °C/min and a total firing time of 2 h	[32]
Bone ash	21 days of air drying	Fired at 100 °C, 300 °C, 600 °C, and 900 °C	[33]

3.Materials and methods

Soil, fly ash, MWCNT potable water, and sodium hexametaphosphate (SHMP) as a surfactant was used in the current study.

3.1Soil

The soil used in the current study was collected from Deogaon, Azamgarh situated in the Uttar Pradesh province of India. The soil was dug from a depth of 2 m below the ground and was categorized as intermediate plastic clay (CI) as per the Indian Soil Classification System. The soil was further characterized using scanning electron microscopy-energy dispersive spectroscopy (SEM-EDS) and x-ray diffraction (XRD). The particle size distribution of the soil used in the study is depicted in *Figure 4* and the soil used is shown in *Figure 5*. The consistency limits of the soil used in the study were ascertained as per the procedures given in IS 2720 Part-5 (IS 1985) [34] and are given in *Table 2*. The surface morphology of the soil used in the study was observed through scanning electron microscopy (SEM) images (*Figure 6*). It shows the irregular shape and rough surface of the soil. The elemental composition of the soil was determined using energy dispersive spectroscopy (EDS) as shown in *Figure 7*. Two EDS spots and four areas were focused on in the EDS analysis to find the elemental composition of the soil. The elemental composition is given in *Table 3*. The result of EDS confirms the presence of silicon (Si) and Aluminium (Al) in appreciable quantity. The presence of other elements in smaller quantities is enumerated in *Table 3*.

Table 2 Consistency limits

Index	Liquid limit (%)	Plastic limit (%)	Shrinkage limit (%)	Plasticity index	Specific gravity
Value	32.17	20.82	16.29	11.35	2.73

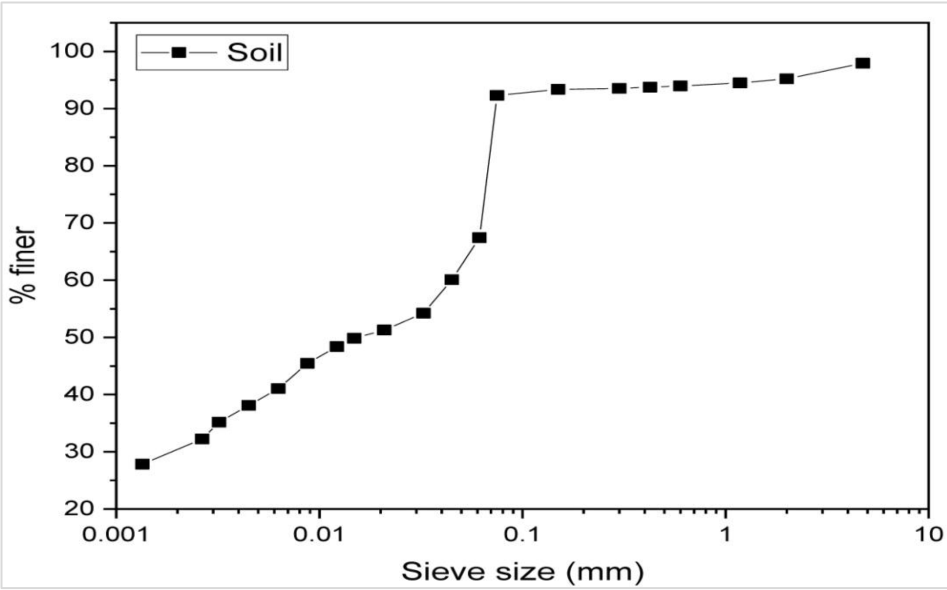

Figure 4 Particle size distribution of soil

Table 3 Elemental Composition of Soil (Wt.=Weight, At. =Atomic)

Element	Area-1		Area-2		Area-3		Area-4		Spot-1		Spot-2	
	Wt. %	At. %	Wt. %	At. %	Wt. %	At. %	Wt. %	At. %	Wt. %	At. %	Wt. %	At. %
O	51.6	65.4	49.4	63.1	51	65.6	51.1	65.5	47.3	62.5	53.6	68.3
Fe	3.4	1.2	3.1	1.1	4.6	1.7	5.6	2.1	7	2.7	3.8	1.4
Cu	0	0	0	0	0.1	0	0	0	-	-	-	-
Na	4.6	4.1	5.1	4.6	-	-	3	2.7	-	-	-	-
Mg	1.6	1.4	1.7	1.4	3.2	2.7	3.3	2.8	4.3	3.7	2	1.7
Al	11.9	9.0	12.9	9.8	13	9.9	12.3	9.4	16.2	12.7	11.4	8.6
Si	24.7	17.9	26.5	19.3	24.9	18.3	22.9	16.8	22.9	17.2	23.7	17.2
K	2.1	1.1	1.3	0.7	3.2	1.7	1.8	0.9	2.2	1.2	5.6	2.9

Figure 5 Soil

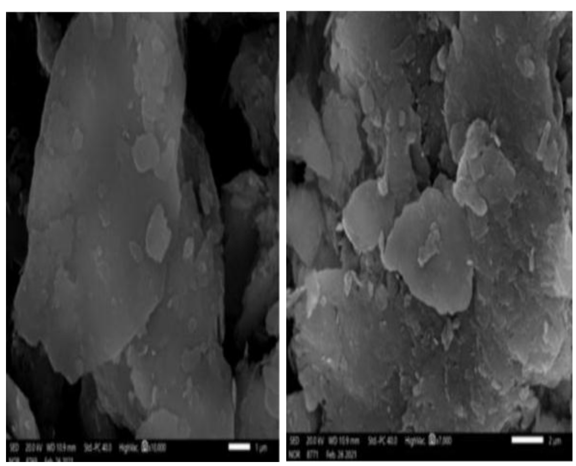

Figure 6 SEM images of soil

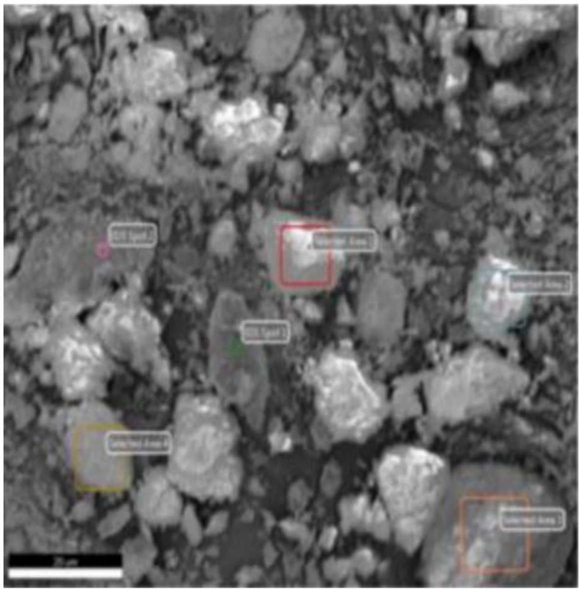

Figure 7 EDS areas and spots in soil

3.2Fly Ash

Fly ash used in the current study was obtained from local interlocking brick manufacturing unit situated at Deogaon, Azamgarh in Uttar Pradesh province of India. The fly ash obtained was dried in an oven at a temperature of 105 degrees Celsius for 24 hours before its use in the brick manufacture. The particle size distribution of fly ash is given in *Figure 8*. SEM-EDS analysis was also carried out to understand the morphological characteristics and elemental composition of the Fly Ash (*Figure 9*) used in the study. SEM images (*Figure 10*) of fly ash show the granular structure and the particles are spherical. EDS (*Figure 11*) highlights the presence of Si in appreciable quantities at every spot and area selected for the analysis. The elemental composition of fly ash is enumerated in *Table 4*. The high Si content can be attributed to class F fly ash.

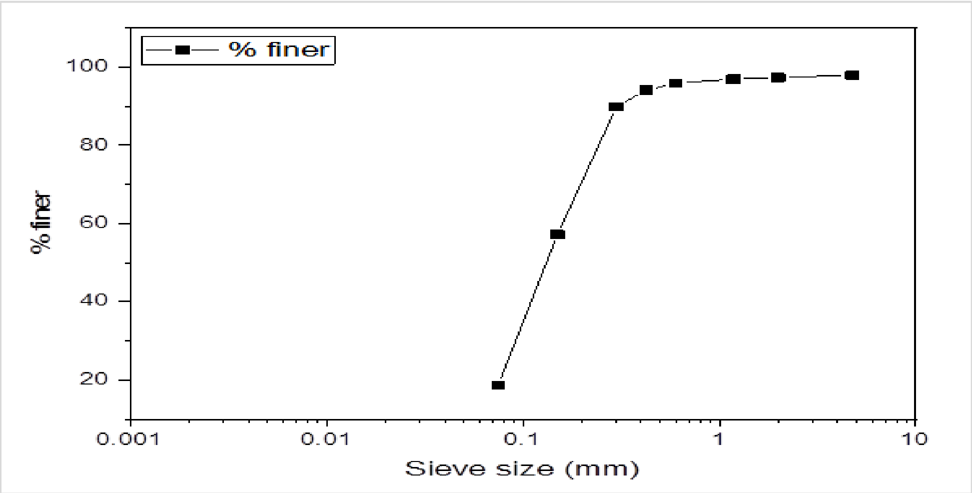

Figure 8 Particle size distribution of fly ash

Table 4 Elemental composition of fly ash

Element	Spot-1		Spot-2		Area-1		Area-2		Area-3	
	Weight %	Atomic %	Weight %	Atomic %	Weight %	Atomic %	Weight %	Atomic %	Weight %	Atomic %
O	36.8	55.5	47.3	66.8	50.5	64.3	47.2	59.1	41.7	48.2
Fe	3.8	1.6	22	8.9	2.5	0.9	-	-	1.3	0.4
Mg	0.7	0.7	-	-	1.2	1	1	0.8	0.4	0.3
Br	12.8	3.9	-	-	-	-	-	-	13.5	3.1
Al	9.6	8.6	8.5	7.1	21.8	16.5	16.4	12.2	1.1	0.8
Si	31.4	27	19	15.3	23.2	16.8	24.4	17.4	16.1	10.6
K	2.6	1.6	3.2	1.8	0.9	0.5	4.6	2.4	1.4	0.7
Ti	2.2	1.1	-	-	-	-	2	0.8	1.5	0.6
C	-	-	-	-	-	-	4.4	7.3	22.9	35.3

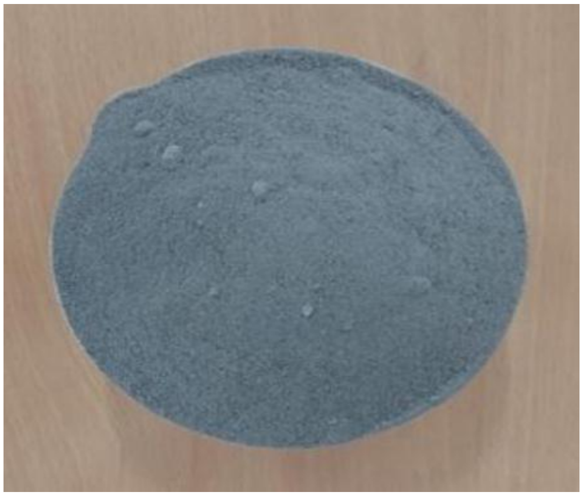

Figure 9 Fly ash

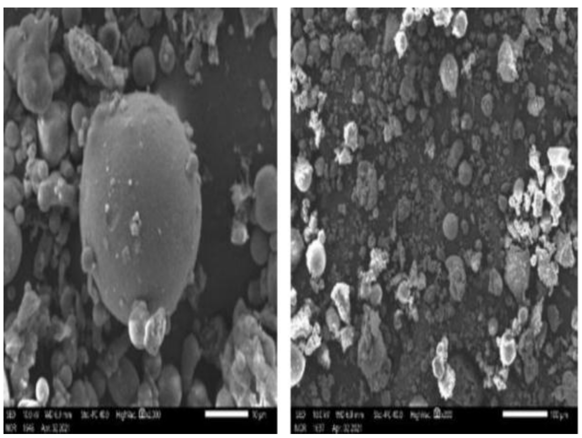

Figure 10 SEM images of fly ash

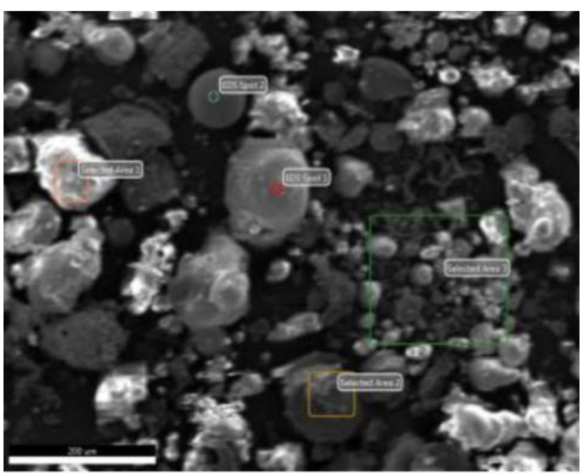

Figure 11 EDS areas and spots in fly ash

3.3Multiwalled carbon nanotube

MWCNT (*Figure 12*) used in the study was synthesized using the chemical vapour deposition (CVD) method. The detailed description of MWCNT used in the study is enumerated in *Table 5*. SEM-EDS analysis was also conducted to understand the surface morphology and elemental composition of MWCNT. SEM images (*Figure 13*) show a tubular, entangled structure of MWCNT. Three areas (*Figure 14*) were focused on using EDS to ascertain the elemental composition of MWCNT. The elemental composition (*Table 6*) of MWCNT shows the presence of carbon in a substantial quantity which is attributed to the purity of MWCNT used in the study. XRD (*Figure 15*) of MWCNT used in the study also confirms the presence of a plane of carbon atoms.

Figure 12 MWCNT

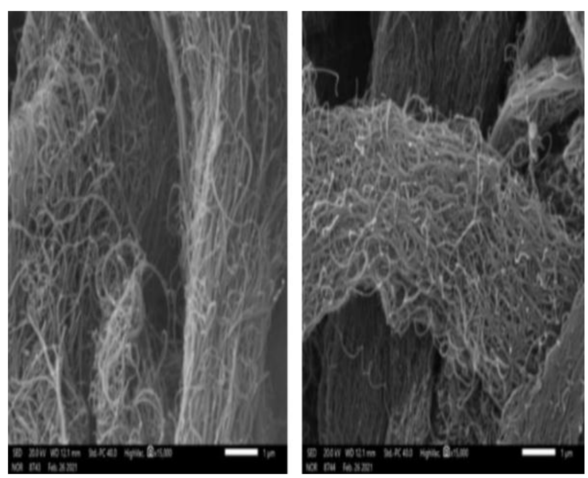

Figure 13 SEM images of MWCNT

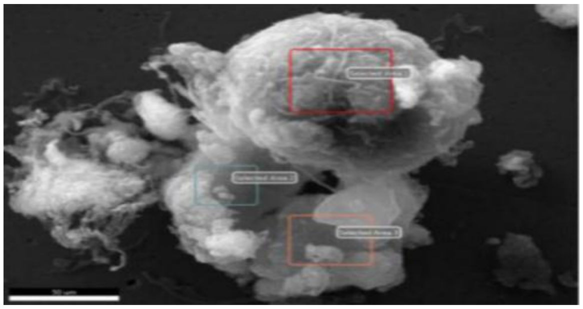

Figure 14 EDS areas and spots in MWCNT

Table 5 Properties of MWCNT

MWCNT	Description
Purity	~99%
External Diameter	~10 x10^{-9} to 30 x10^{-9} m
Internal Diameter	~5 x10^{-9} to 10^{-8}m
Length	> 10^{-5}m
Surface Area	110 to 350 m^2/g
CNT Content	95 to 99%
Bulk Density	0 .04 g/cm^3
Chemical Formula	C
Physical Form	Fluffy, Very Light Powder
Odour	Odourless

Table 6 Elemental composition of multiwalled carbon nanotubes

	Area-1		Area-2		Area-3	
Element	**Weight %**	**Atomic %**	**Weight %**	**Atomic %**	**Weight %**	**Atomic %**
C	90.7	93.4	82	86.5	68.39	76.7
O	7.4	5.8	14.5	11.5	23.4	19.5
Na	0.7	0.4	1.2	0.6	2.5	1.5
Al	0.3	0.2	0.5	0.2	0.5	0.3
Si	0.6	0.3	1.3	0.6	3.4	1.6
Ca	0.1	0	0.1	0	0.3	0.1
Fe	0.2	0	0.2	0	0.2	0.1
Mg	-	-	0.3	0.1	0.4	0.2
K	-	-	-	-	0.1	0.0
Co	-	-	-	-	0.1	0.0

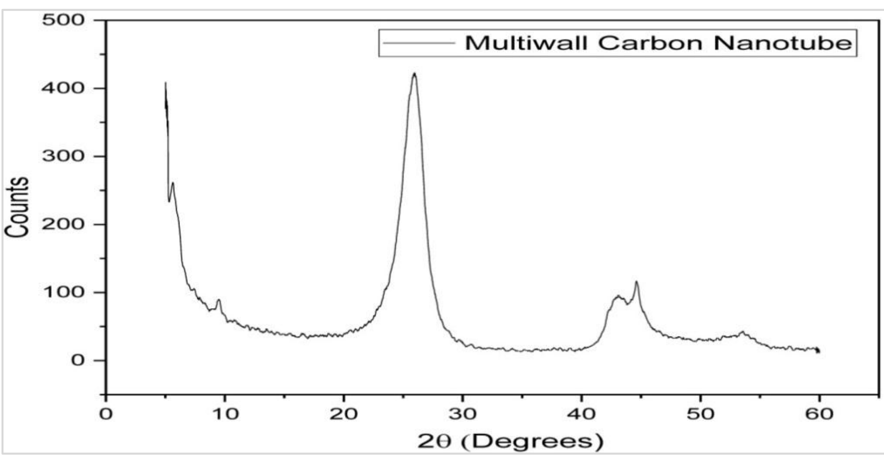

Figure 15 XRD diffractogram of MWCNT

3.4Manufacturing of Bricks

Bricks of cylindrical shape (Diameter: Depth: 3.8 cm: 7.6 cm) were made from intermediate plastic clay (CI). The clay portion of the brick was subsequently replaced in proportions such as 10%, 20%, 30%, 40%, 50% by class F fly ash. The water used to prepare the soil for making bricks was doped with 0.001%, 0.01%, 0.1% MWCNT weight by weight of water. SHMP was used along with MWCNT to promote its dispersion in the aqueous medium. A total of 24 combinations of cylindrical bricks as enumerated in *Table 7* were made and 3 samples of each kind were prepared.

Preparation of soil: The soil used in the study was oven-dried at 105 degrees Celsius for 24 hours and then mechanically pulverized, using wooden hammers into smaller fragments such that no lumps are present in the soil. Then the soil passing through a 425-micron sieve was used to make the cylindrical specimen. Distilled water was then added in such a quantity that a workable paste can be obtained which can be easily extruded through a mould of 3.8 cm diameter. MWCNT dispersions (Distilled Water + MWCNT + SHMP) (*Figure 15(a)* to *(c)*) were used in place of distilled water when MWCNT doped bricks were to be made. The soil paste was manually extruded through an unconfined compressive strength sampler available in the laboratory.

Drying conditions: The prepared bricks were initially sun-dried for 24 hours and then oven-dried for 24 hours at 105 degrees Celsius. This was done to avoid shrinkage cracking due to the sudden expulsion of water from the soil matrix.

Baking conditions: The oven-dried bricks were then transferred to a muffle furnace, which was preheated at a temperature of 900 degrees Celsius. The bricks were kept in a muffle furnace for 6 hours at 900 degrees Celsius and were left in the same condition for 12 hours after stopping the muffle furnace. *Figure 16 (a) to (f)* depicts the steps involved in cylindrical brick preparation. The following section presents the discussion on the results obtained through various tests. *Figure 17* shows the entire mechanism involved in brick production in the form of a sequential block diagram.

Table 7 Combinations used in Bricks

Soil (%)	**Fly Ash (%)**	**MWCNT (% w/w)**	**SHMP (% w/w)**
100	0	0, 0.001, 0.01, 0.1 respectively	0, 1 (SHMP was used only in conjunction with MWCNTs)
90	10		
80	20		
70	30		
60	40		
50	50		

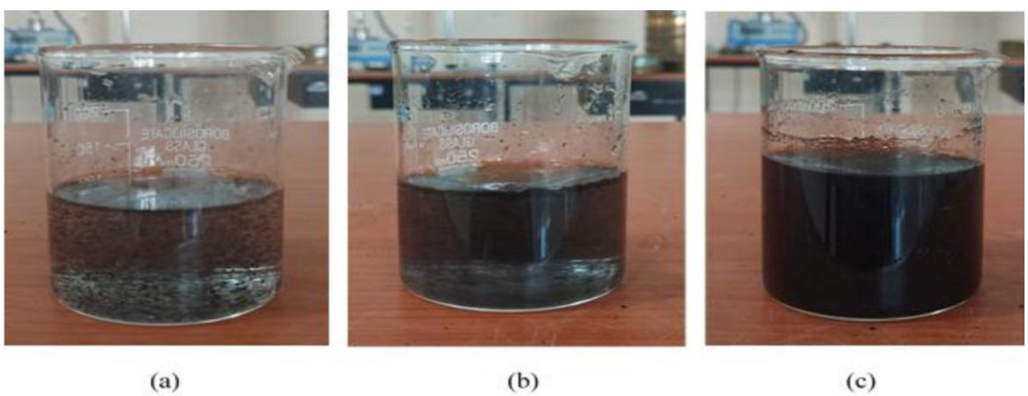

Figure 15 MWCNT Dispersion (a) 0.001% w/w (b) 0.01% w/w (c) 0.1 % w/w

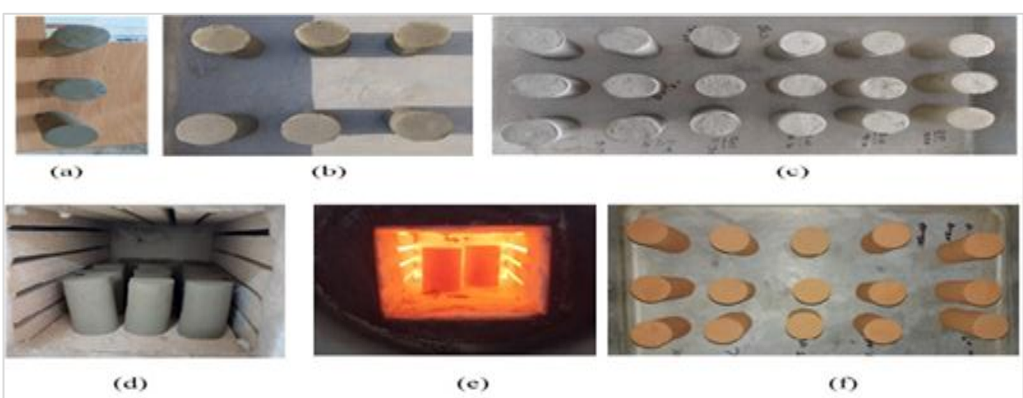

Figure 16 Steps involved in the brick preparation (a) Freshly moulded bricks (b) sun dried bricks (c) oven dried bricks (d) bricks in a muffle furnace cavity (e) baking in operation (f) muffle baked bricks

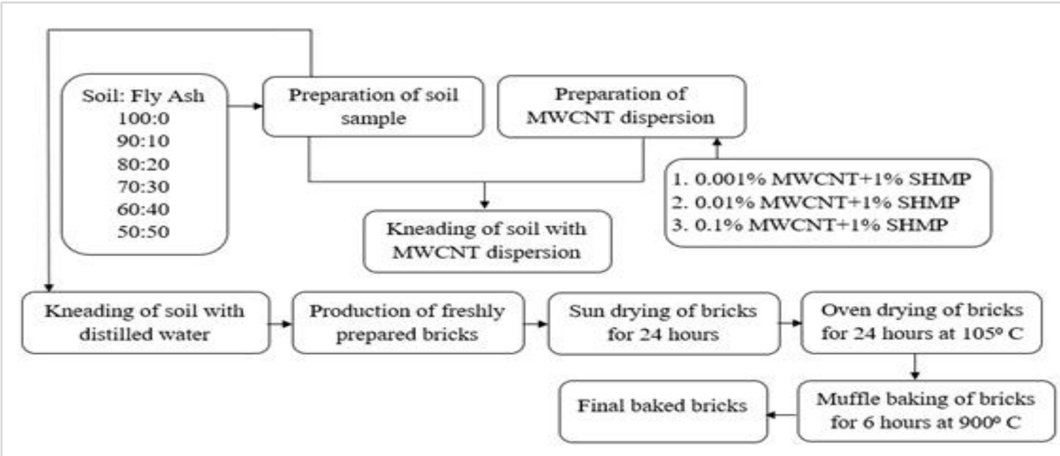

Figure 17 Mechanism of production of bricks

4.Results and discussions

Muffle-baked fly ash reinforced bricks doped with MWCNT were subjected to various engineering tests such as visual examination, hardness test, soundness test, structure test, water absorption test, compressive strength test, initial rate of absorption, bulk density. The current section comprehensively presents the various test results and its implications on different important properties of bricks.

Muffle-baked fly ash reinforced bricks doped with MWCNT were subjected to various engineering tests such as visual examination, hardness test, soundness test, structure test, water absorption test, compressive strength test, initial rate of absorption, bulk density. The current section comprehensively presents the various test results and its implications on different important properties of bricks.

4.1Visual examination

The bricks so formed after muffle baking were visually examined for any deformity, distortions, etc. It was observed that the outer surface becomes smoother with the increase in fly ash content. Some voids and distortions were seen in the muffle baked samples containing clay in higher quantities. The bricks with higher clay contents were aesthetically more pleasant.

4.2Hardness test

A sharp object was used to scrape the exposed surfaces of the bricks in the hardness test. The bricks with higher fly ash content recorded more significant scratches than the bricks with lower fly ash content. The least scratches were observed on the pure clay bricks.

4.3Soundness test

The resilience of bricks to a sudden strike/impact is determined by the soundness test. When two bricks are hit together abruptly, a sound brick should not fracture and should create a metallic ringing sound. The test was carried out on all the bricks. The metallic sound was observed in all the bricks, but the intensity of loudness decreased with the increase in fly ash content.

4.4Structure test

Due to a lesser degree of densification, voids in the internal structure of burned bricks may develop. A homogeneous internal structure was observed in all the bricks. The homogeneous internal structure of bricks can be seen in *Figure 18*. Bricks free from any internal deformities are considered durable in engineering practices.

Figure 18 Homogeneous internal structure

4.5Water absorption test

Water absorption is one of the prominent characteristics of the brick. A good quality brick should be able to block the seepage of water from the exposed faces. It directly affects the strength of the masonry structure as high water absorption leads to reduced bond strength between brick faces and mortar. The cylindrical bricks were oven-dried for 24 hours at 105 degrees Celsius. The bricks were then weighed (w1) and immersed for 24 hours in potable water as shown in *Figure 19*. After 24 hours, the weight (w2) of the bricks was recorded and water absorption of the bricks was calculated as per Equation 1.

$$Water\ Absorption\ (\%) = \frac{W2 - W1}{W1} \times 100 \quad (1)$$

The maximum water absorption was seen in bricks made with 50 % replacement of soil with fly ash doped with 0 % MWCNT. The value of water absorption showed a gradual increase with the increase in fly ash in the soil. A decrease in water absorption was observed with the increase in MWCNT content in the soil-fly ash mixture. *Figure 20* shows the water absorption of various types of bricks. The results of the water absorption test are enumerated in *Table 8*. The reduction in water absorption is made possible by the improved vitrification of particles and reduction in pores in the body of bricks due to the presence of MWCNT. This decrease in the water absorption of bricks due to the inclusion of MWCNT in the soil-fly ash matrix may also be attributed to the void filling ability and high adsorbing nature of MWCNT. The less water that penetrates brick samples, the more durable the samples.

Table 8 Water absorption (%) of bricks

Soil (%)	Fly Ash (%)	MWCNT (%) w/w of water			
		0	**0.001**	**0.01**	**0.1**
100	0	13.63	13.28	12.67	12.60
90	10	14.46	14.32	12.95	12.93
80	20	15.40	15.28	15.09	12.97
70	30	16.15	15.58	15.12	14.60
60	40	17.55	17.24	16.86	14.74
50	50	19.35	18.03	17.79	17.66

Figure 19 Water absorption test

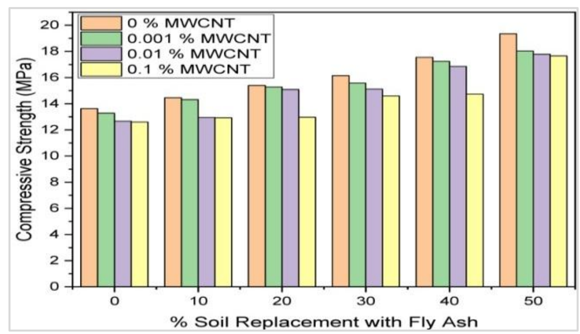

Figure 20 Water absorption of various types of bricks

4.6Compressive strength test

The compressive strength of bricks is one of the most important properties. It assures their engineering excellence and gives information on their suitability for use in different masonry structures. The cylindrical brick specimen was inserted between the flat plates of the testing equipment of 200kN capacity to perform mechanical compressive strength testing as shown in *Figure 21*. As indicated in *Figure 21*, an axial force was applied until the bricks were fractured. The compressive strength was then determined by dividing the highest load by the average brick face area. *Figure 22* depicts the compressive strength of different categories of bricks. As the amount of fly ash in the brick samples rose, the compressive strength of the samples fell considerably. Compressive strength and fly ash have an inverse connection. The growing volume of capillary pores, which is related to rising fly ash replacement levels, might explain the negative connection between compressive strength and fly ash concentration. It's also worth noting that increasing the MWCNT concentration enhanced the compressive strength substantially. The increase in compressive strength of the bricks due to the introduction of MWCNT in the matrix may be attributed to the high mechanical strength and micro level void filling ability of MWCNT. The compressive strength of the bricks achieved at various clay replacement ratios and doping concentrations is higher than the Indian Standards' minimum requirement of 3.5 MPa for compressive strength. The results of compressive strengths corresponding to different MWCNT concentrations are enumerated in *Table 9*.

Table 9 Compressive strength (MPa) of bricks

Soil (%)	Fly Ash (%)	MWCNT (%) w/w of water			
		0	0.001	0.01	0.1
100	0	15.32	16.46	18.24	19.23
90	10	14.92	15.46	17.17	18.23
80	20	13.75	14.87	16.76	17.96
70	30	11.67	13.43	15.90	16.86
60	40	10.42	11.13	12.77	15.95
50	50	6.35	7.24	8.65	9.38

Figure 21 Compressive strength test

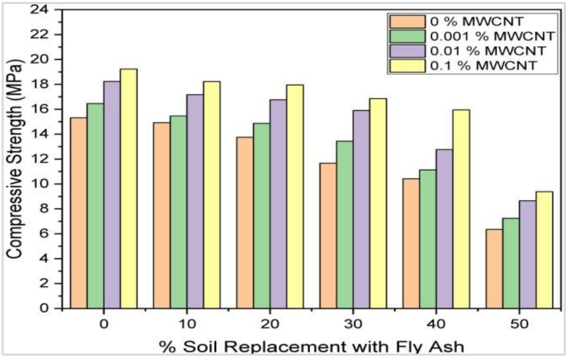

Figure 22 Compressive strength of bricks

4.7Initial rate of absorption

The initial rate of absorption or suction rate of bricks is determined by measuring the weight gain over time when the face of the brick specimens is immersed in water. The lower suction rate of bricks is associated with their high durability of bricks. An increase in suction rate was seen in bricks with the increase in fly ash in the matrix. *Figure 23* depicts the suction rates of various brick specimens.

The minimum suction rate of 0.85 kg/m2/min was observed for pure clay bricks with 0.1 % MWCNT w/w of water and the maximum suction rate of 1.98 kg/m2/min was recorded for brick specimens with 50 % fly ash replacement with no MWCNT. It is observed that the suction rate of bricks is directly proportional to the presence of fly ash and inversely proportional to the presence of MWCNT in the soil-fly ash matrix. The suction rate of bricks with high fly ash content is on the greater side because of the high water absorption capacity of fly ash.

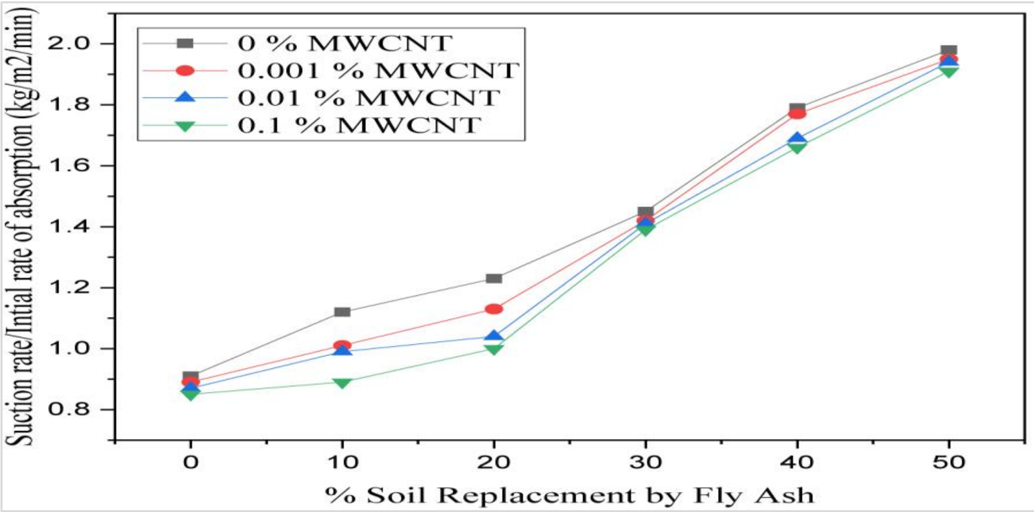

Figure 23 Initial rate of absorption/ Suction rate of bricks (kg/m2/min)

4.8Bulk density

The bulk density of bricks is obtained by diving the dry weight of the brick specimen by its volume. *Figure 24* shows the bulk densities of bricks of different compositions. It was observed that the bulk density of bricks decreases with the increase in fly ash content. This decrease in the bulk density is due to the much lower specific gravity of fly ash as compared to clay. A slight increase in the bulk density is seen with the increase in the concentration of MWCNTs in the soil- fly ash matrix. This increase is attributed to the highly absorbent nature of MWCNT and the use of SHMP in the soil-fly ash matrix. A maximum value of 1.59 gm/cc was observed for pure clay brick with 0.1 % MWCNT w/w of water and a minimum value of 1.35 gm/cc was recorded for brick specimen with 50 % clay replacement by fly ash without the use of MWCNT in the soil-fly ash matrix.

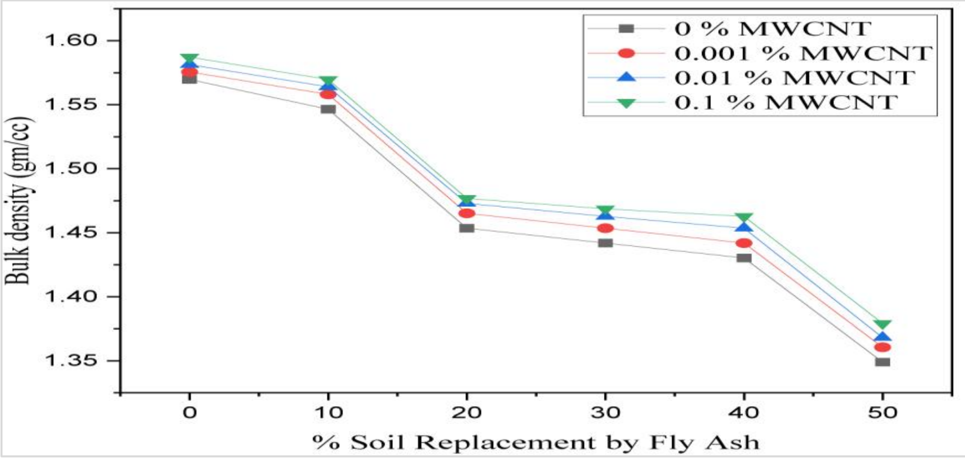

Figure 24 Bulk density of bricks (gm/cc)

4.9Energy and time savings

Conventional Bricks are fired at the temperature of 800-1200 degrees Celsius and are ready after 20-30 days. In the current study, bricks were fired at 900 degrees Celsius for 6 hours and were left in the muffle furnace overnight. The entire process of brick production right from soil preparation to final baked bricks took 3 days. The methodology adopted during the study took 17-27 days less than the time taken to produce conventional brick. The muffle furnace was in operation for 6 hours only, the energy savings were also very substantial.

4.10Limitations

The study exclusively focused on the effect on the utilization of MWCNTs in the presence of fly ash as reinforcement. MWCNTs were always used in conjunction with SHMP to promote its dispersions. The dispersion of MWCNTs can also be easily promoted by the application of ultrasonic energy in the aqueous medium. The usage of ultrasonic energy may cut the total cost of production by eliminating the use usage of SHMP. The cost of MWCNT is an important factor and its dosage must be carefully examined. Microstructural examination of final baked bricks can add more insights to the study. The structural changes in the bricks at different stages of the production process can be easily understood by the microstructural examinations. The study was conducted on a small scale (in an academic laboratory), record some variations in the results may be recorded at large-scale production of such bricks. A complete list of abbreviations is shown in *Appendix I.*

5.Conclusions and future work

Mechanical tests revealed that bricks with acceptable mechanical characteristics may be made with up to 50% fly ash from thermal power plants. The maximum compressive strength was observed at 0.1% MWCNT doping. The addition of fly ash to the clay raises the water content necessary for plasticity. At the used MWCNT concentrations, fly ash does not cause any problems during shaping. There were no failures in the extrusion process. At 900 degrees Celsius, the addition of up to 50% by weight of fly ash has no negative effect on the brick quality, but clay does not readily absorb more fly ash without affecting the brick quality. This is supported by the fact that as the amount of fly ash in bricks increases, the compressive strength of the bricks decreases. These low-density bricks (fly ash is lighter than soil) can be used to substitute pure clay bricks in multistory buildings to reduce dead weight and are especially useful for multistory partition construction. This study demonstrates that combining fly ash and MWCNT into clay brick generates high-quality masonry bricks, and it is obvious that clay–fly ash bricks may effectively handle concerns such as fly ash disposal, pollution, production costs, and prudent preservation of the natural resource clay. The shortened time of production of these bricks can also be helpful to cope with the increasing demand for bricks.

The current study can be extended by analyzing the effect of MWCNTs without the use of SHMP in the aqueous medium. The effect of ultrasonic energy in the dispersion of MWCNT can also be studied. SHMP can also be added as an exclusive additive to the brick soil as it controls the preferential orientation of soil particles and thereby increasing the overall stability of the soil. A comprehensive microstructural examination can be carried out to understand the structural changes in the baked bricks.

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Conflicts of interest
The authors have no conflicts of interest to declare.

Authors' contribution statement
Anish Kumar: Conceptualization, experimental work and formal writing. **Sanjeev Sinha:** Conceptualization, methodology, editing, and review.

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Appendix I

S. No.	Abbreviation	Description
1	CI	Intermediate Plastic Clay
2	CNF	Carbon Nanofibers
3	CVD	Chemical Vapour Deposition
4	EDS	Energy Dispersive Spectroscopy
5	MWCNT	Multiwalled Carbon Nanotubes
6	SEM	Scanning Electron Microscopy
7	SEM-EDS	Scanning Electron Microscopy-Energy Dispersive Spectroscopy
8	SHMP	Sodium Hexametaphosphate
9	XRD	X-Ray Diffraction