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Properties of flyash based wood geopolymer composite

B. S. Mamatha[1*], D. Sujatha[2], D. N. Uday[2] and M. C. Kiran[1]

Abstract

Geopolymers are inorganic adhesive synthesized from industrial waste such as fly ash thus the development of wood geopolymer composite would be a low carbon footprint material. Geopolymers, being a non-formaldehyde adhesive can be used as an alternative binder for wood based composites where environmentally friendly and sustainability of product is important. In this study flyash as precursor is been used in the development of wood geopolymer composite product. Flyash is activated with a combination of sodium hydroxide and sodium silicate solutions at a weight ratio of 1:2.5 for geopolymer formation. The study investigated the properties of wood geopolymer composite made with ratios of wood particle to flyash percentage (23/77), (37/62), (44/55), (50/50) and (57/43). Geopolymer formation was observed by X-ray Diffraction (XRD) and Fourier transform infrared spectroscopy (FTIR). Influence of wood particles in wood geopolymer composite were observed by Scanning electron microscope. The study shows that the water absorption and thickness selling properties of all the formulations of wood geopolymer composites are comparable with the medium density particle board and cement-bonded particleboard according to the IS:3087–2005 standard and IS: 12406: respectively. Highest mechanical properties and good bond strength was obtained by the composite containing 23% wood particle ratio with 77% percent flyash. However, still improvement in mechanical properties is needed to achieve the mechanical properties comparable to cement bonded particle board.

Keywords Geopolymer, Composite, Wood particle, Inorganic adhesive, Flyash

摘要

地聚合物是由粉煤灰等工业废弃物制备而成的无机胶凝材料，故木质地聚合物复合材料是一种低碳材料。由于产品的环保性和可持续性很重要，作为一种不含甲醛的胶黏剂，地聚合物可以用作木质基复合材料的替代胶黏剂。在本研究中，粉煤灰作为前驱体用来制备木质地聚合物复合材料。通过使用质量比为1∶2.5的氢氧化钠和硅酸钠溶液作为激发剂激发粉煤灰，从而制备地聚合物。本文研究了木质颗粒与粉煤灰的比例分别为(23/77)、(37/62)、(44/55)、(50/50)和(57/43)的木质地聚合物复合材料的性能。采用X射线衍射(XRD)和傅立叶红外光谱仪(FTIR)分析了地聚合物的反应产物。并且，通过扫描电镜表征了木质颗粒对木质地聚合物复合材料的影响。结果表明，根据IS：3087-2005标准和IS：12406标准，所有配方的木质地聚合物复合材料的吸水性和厚度膨胀性均与中密度刨花板和水泥刨花板相当。当木质颗粒和粉煤灰含量分别为23%和77%时，复合材料具有最优的力学性能以及良好的粘结强度。然而，上述复合材料要达到与水泥粘合刨花板相当的力学性能，仍需对其做进一步改进。

关键词 地聚合物，复合材料，木质颗粒，无机胶黏剂，粉煤灰

*Correspondence:
B. S. Mamatha
mamathabs888@gmail.com
Full list of author information is available at the end of the article

1 Introduction

Wood based panel products requires adhesives for the manufacture of composites. Adhesives generally used are formaldehyde based adhesives such as urea formaldehyde adhesive. Formaldehyde emission from the panels is legally restricted as formaldehyde is carcinogenic in nature. One such method is to use inorganic adhesive which is formaldehyde free for the manufacture of wood composite. Wood particles has been combined with inorganic binder such as cement to obtain composite materials with unique properties. These inorganic-bonded wood composites viz cement bonded particle board is very resistance to deterioration by decay fungi, insects, fire and water resistant [1].

Alternative to cement another environmentally friendly, inorganic binder material developed is Geopolymer. They are amorphous, three-dimensional alumino-silicate materials consisting of repeating units silico-oxide (-Si–O-Si–O-), silico-aluminate (-Si–O-Al-O-), created through a process of geopolymerization, [2]. Generally, in the geopolymerization process sodium silicate (Na_2SiO_3) or potassium silicate (K_2SiO_3) in combination with sodium hydroxide (NaOH) or potassium hydroxide (KOH) serve as alkali activators to activate the aluminosilicate precursors such as flyash, slag etc. [3]. Industrial waste materials such as flyash, slag etc consists of silica, alumina hence act as precursors for the synthesise of geopolymer.

Lot of research on utilisation of flyash as precursors for geopoolymer formation in wood geopolymer composites has been studied. Alomayri et al., 2013 [4] reported that the addition of cotton fibers can improve the mechanical properties of geopolymer composites. Chen et al., 2014 [5] investigates the reinforcement of fly ash-based geopolymer with alkali-pretreated sweet sorghum fiber up to 2% increased both tensile and flexural strengths of the geopolymer composites. Sarmarin et al., 2015 [6] has produced light weight geopolymer wood composite using 10% wood particles of size 3-5 mm as reinforcement along with class F fly ash and metakaolin for load bearing applications. Fly ash-based geopolymer reinforced with 0 – 20% sawdust reported that the inclusion of fibre, more than 5% affected the workability and setting time. Geopolymers without sawdust exhibit cracks and high porosity ratio after 28 days curing [7]. Alomayri et al., 2014 [8] studied the mechanical properties of fly ash geopolymer reinforced with cotton fabric at elevated temperature. The addition of fibres prevented the matrix from cracking after exposure to a high temperature range of 200 – 1000°C. Geopolymers can be cured both at ambient conditions and slightly elevated temperatures. The curing conditions, such as temperature and duration of curing can significantly affect evolution of strength development of the final product [9]. Geopolymers cured at elevated temperature have been reported to exhibit better strength properties.

Thus Geopolymers can act as an alternative binder for wood-based composites where environmental friendly, durability, and sustainability of product is significant. And utilising flyash an industrial by-product for synthesise of geopolymer make this inorganic binder a low carbon foot print. In India 179 thermal plants generates flyash of about 222 million tonnes. Though flyash utilisation in India has increased from 10% in 1997 to 92% in 2020–21 in the construction industry, bricks etc. However still 17million tonnes of flyash is unutilised. Government of India has prohibited dumping and disposal of fly ash in landfill. Hence the study was taken to utilise this flyash to synthesise geopolymer for the manufacture of wood geopolymer composite using wood particles.

Although many research has been conducted on development of wood geopolymer composite using wood particles, However, all these composites were made by blending wood particle with flyash followed by the addition of alkaline solution for the manufacture of wood geopolymer composite. This work focuses on the development of wood geopolymer composite by blending of wood particles with geopolymer as binder made using Indian flyash. The primary goal of this research was to determine the sorption properties, mechanical strength and internal bond strength of wood geopolymer composite made by the modification of hot pressing conditions. Physical and mechanical properties of wood geopolymer composites, made using different ratio of wood and flyash were evaluated as per IS: 14276 and IS:3087.

2 Materials and methodology

Wood particles of species Grevillea *robusta* having particle length of 0.8 mm to 1.2 mm with the moisture content of 4–5% were used for the study. Sodium hydroxide (Thomas baker) and sodium meta silicate of analytical grade with molar ratio of Na_2O: SiO_2 (1:1.15) are alkaline activators. Fly ash was procured from GR Fly Ash Industries ASHCON (GR Enterprises Group, Bangalore). The properties of fly ash such as Loss of ignition, Bulk density, pH and moisture content were analyzed. Following methods were employed for the analysis of Flyash.

Determination of Loss on Ignition: Weighed 1 g of dry sample in platinum crucible. Placed this crucible in muffle furnace at a temperature below 300 °C. Raise the temperature of the furnace to 1000^{O}C. Keep this at the 1000^{0}c temperature for about 30 min. After cooling the crucible in desiccator, weight of the crucible is taken. Percentage Loss on Ignition was

calculated using Loss in weight × 100/Weight of the sample.

Moisture content: Fly ash of about 2 g was placed in hot air oven at 103^0C for 3 h and oven dry mass is taken. Further the sample is replaced in oven and after every 1 h oven dry mass was taken until getting constant mass. moisture content (%) was calculated using initial mass – oven dry mass/oven dry mass.

pH: About 4 g of fly ash was soaked in boiled and cooled 40 g of distilled water. After 72 h of soaking, the pH was measured using electrode method in pH meter.

Bulk density: Oven-dried samples were placed in a 25 ml cylindrical container and the bulk density is determined as the ratio of the mass to the volume of the container. = $Mo/\ Vc$ where Mo (g) is the oven dry mass of flyash, Vc (cm^3) is the volume of the container.

2.1 Manufacturing process

Geopolymer binder results from the activation of aluminosilicate powder, in this study Flyash is used as aluminosilicate powder. The alkaline activator was prepared by admixture of one-part sodium hydroxide (10N) to the 2.5 parts of sodium silicate. Sodium hydroxide solution was prepared and cooled to ambient temperature before mixing with sodium silicate.

2.1.1 Preparation of geopolymer binder

Geopolymer binder was prepared using alkaline solution, and the alkaline solution was prepared 1 day prior to the use. The required quantity of Flyash powder was added to the alkaline solution. Blending was continued until a homogenous mixture of ingredients was achieved. The mass ratio of sodium silicate to the sodium hydroxide, were kept constant in all variations. Table 1 shows the quantity of materials in parts taken for the study.

2.2 Characterization and testing

FTIR and XRD diffractogram of Flyash, and Geopolymer were analyzed to understand the formation of geopolymerisation. XRD was measured with a D8 Focus (Bruker) X ray diffractometer and scanned from 3 -15 with a step size of 0.04 and o.8 s s/step. X ray radiation was generated by using a 35 kV, 40 mA cobalt radiation source. The FTIR spectra (perkin Elmer) were obtained using oven dried samples.

Elements of the flyash was measured in EDAX and the cross sectional images of SEM. Samples were gold coated to increase the electrical conductance for SEM analysis.

Table 1 Formulation of boards

Sample No	Wood particles (parts)	Alkaline solution(parts)	Fly ash (parts)
A,P	23	53.9	77
C1	37	43.4	62
X	44	38.5	55
Y	50	35.0	50
Z	57	35.0	43

2.3 Formulation of boards

Flyash to alkaline activator ratio of 0.7 was fixed. The mass ratio of sodium silicate to the sodium hydroxide, were kept constant in all variations. Sample containing 23% wood particles and 77% flyash was named as A/P. Similarly, wood particles to flyash varied proportions namely C1 (37/62) containing 37% wood particles with 62% flyash. Whereas (44/55), (50/50) and (57/43) named as X, Y and Z respectively were taken for the study is as tabulated in Table 1.

2.4 Manufacturing of wood geopolymer composite

The targeted dimension for the manufacturing of wood geopolymer composite is 300 mm x 300 mm x 12 mm. The binder was added to the wood particle and blended uniformly so as to distribute the adhesion to all the particles. During manual mixing of binder with the particles, entire quantity of particles was taken in a tray and binder was slowly poured on the particles. The ratio of wood particle to flyash was different from each board (Table 1). 2 mm thick aluminum caul plates of the required board dimensions with 10% excess in margin is taken. BOPP film paper is placed over the aluminum caul plate followed by the wooden frame, particles glued with binder were filled inside the frame. Manually glued particles were spread in uniform. A wooden flat lid is placed over the particles with the frame and pressed manually. The frame along with the lid is removed while the material is under pressure. The formed mat was wrapped in the Bopp film after prepressing manually. The mat formed matrix is loaded into the hydraulic hot press (Make BEMCO) along with side bars for the 12 mm thickness at 155^0C. Pressure of 24 kg/cm^2 was applied for 15 min. After stipulated time of pressing, Board was slowly unloaded from press and were placed in oven at 80^0c for curing for 8 h. After 8 h of curing boards were removed from hot air oven and kept at room temperature for stabilization. Flow chart of manufacturing process has been given below as Fig. 1. The board are stacked on a flat platform to attain equilibrium moisture and then trimmed to require sizes. Two

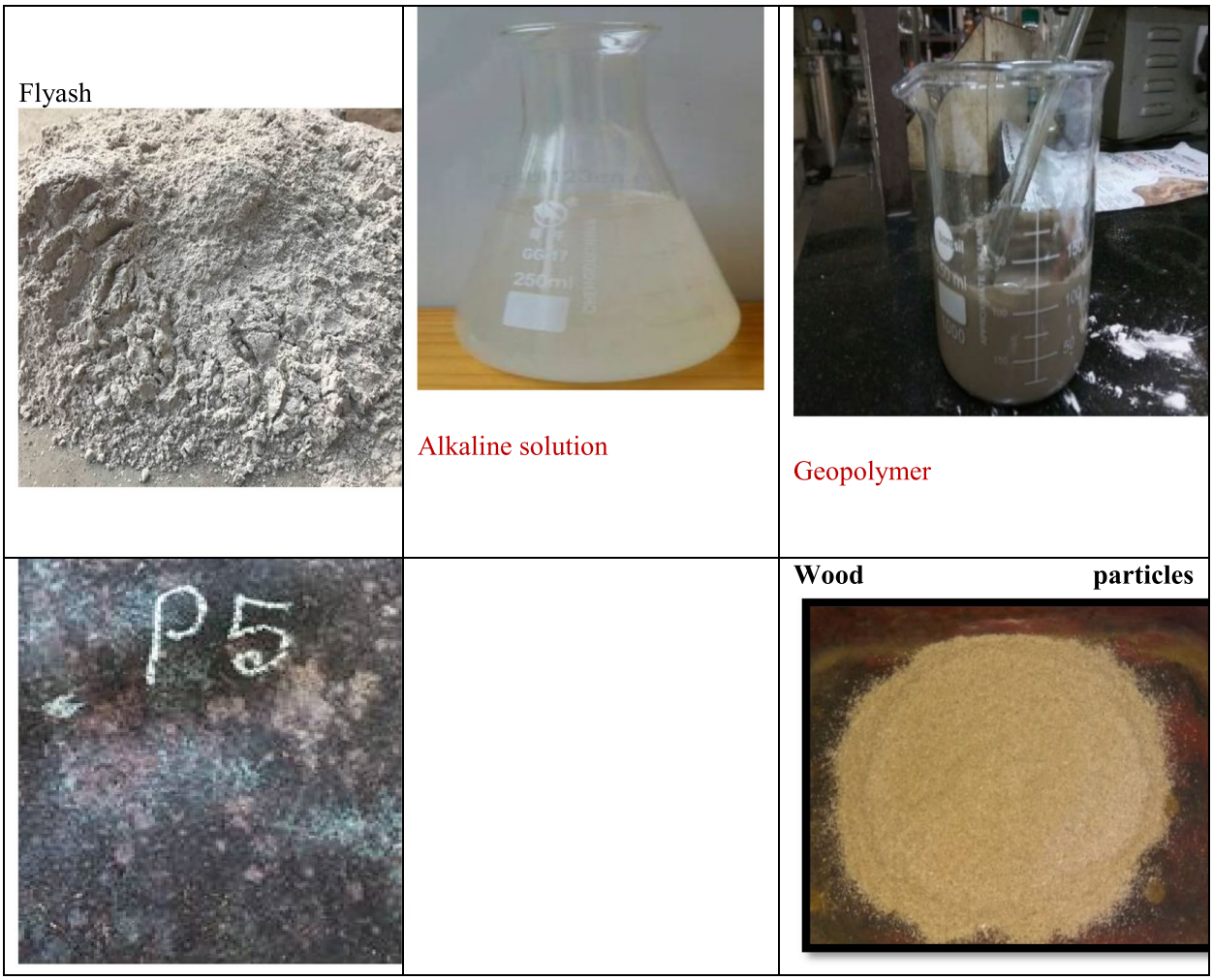


Fig. 1 Flow chart of manufacturing process of wood geopolymer composite

boards of same composition A and P were manufactured but only total quantity of the ingredients in Board P was slightly more, All the boards were sent for cutting or and testing only after 5–6 days of stabilization. All the test specimens were exposed to an atmosphere maintained at relative humidity of 65 ± 5% RH and at a temperature of 27 ± 2^{0}C. Test specimens were kept in this controlled atmosphere until they were tested. The panels were then cut to size and evaluated for the mechanical properties as per IS 3087:2005 and IS: 14276.

2.4.1 Physical and mechanical properties of the samples

The panels made were stored in laboratory for 5 days at ambient temperature. Three replica of each formulation were made and evaluated the properties. After the stabilization of the boards for about 5 days, the panels were cut to the requisite sizes to evaluate the properties as per IS 3087: 2005 and IS: 14276. Three boards of each formulation and 6 samples for each test were used.

Mechanical properties included Modulus of rupture, (MoR), Modulus of elasticity (MoE) and Internal bond strength was tested as per IS 1708(1986). MOR/MOE were tested in UTM of 25KN using 500 kg sensors for the sample size of 300 mm x 75 mm x 12 mm, three-point bending test at a speed of 10 mm per minute was tested as per IS:1708. The testing data were recorded using an Instron 3365 Universal Testing Machine (M/s kalpak instruments private ltd) with a 25kN load cell at a speed of 1 mm/min. The strength (σF) was calculated using the following Eq. (1),

$$\sigma F = 3FL/2bh^2, \tag{1}$$

where F is the maximum load of the specimen (N), L is the specimen span (mm), b is the width of the sample (mm), and h represents the sample thickness (mm).

Internal bond strength was analyzed for the samples so as to evaluate the shear at the glue joint. The specimens with the dimensions of 50 mm × 50 mm were subjected under the shear strength instrument and load was applied to check the load required to pull apart the specimens. Surface failure samples were discarded. Load divided by area would give us the Internal bond strength of the samples in N/mm^2.

Thickness swelling and water absorption: Samples of about 5omm x 50 mm of six replicates were soaked in water at ambient conditions for 2 h. mass of the samples before and after soaking were recorded using weighing balance and thickness was measured using Vernier calipers. Calculations were made as per the below equations. (2) and (3)

$$\text{Thickness swelling} = \textit{final thickness} - \textit{initial thickness}/\textit{initial thickness}\ x\ 100\% \tag{2}$$

$$\textit{Water absorption} = \textit{final weight} - \textit{initial weight}/\textit{initial weight}\ \text{x}\ 100\% \tag{3}$$

3 Results and discussions

Flyash is used as the source of raw material for the formation of geopolymer, wherein the pH of flyash is observed to be pH 9.07 indicating alkaline in nature. Flyash used contained loss of ignition and moisture content 4.8%, 0.05% respectively. Bulk density of flyash found to be 770–800 kg/m3.

3.1 Elemental analysis of fly ash

Elemental analysis of flyash by EDAX (Fig. 2) has shown that the fly ash is having silicon followed by aluminum and calcium. Iron, magnesium, potassium content presence is also found in the flyash Generally Fly ash is composed majorly of acidic oxides such as alumina, silica and ferrite which provide potential for alkali activation [10]. It is inhomogeneous mixture of amorphous alumina silicates, silica glasses and crystalline materials like hematite, magnetite, mullite, and quartz in small quantities [11]. The composition states that the flyash has silica, aluminum and calcium in rich hence will possess both pozzolanic and cementitious characteristics.

3.2 XRD characterisation

Figure 3 shows the XRD pattern of fly ash and geopolymer sample and the peaks representing data in Tables 2 and 3 has been displayed. The diffractogram of fly ash can be seen in Fig. 1(a) representing peaks, while quartz was the phase most widely found at peak (2θ) of 26°. (Table 2) Another phase found in fly ash sample at peak (2θ) of 60° was mullite. The diffractogram of geopolymer sample synthesized from fly ash exhibits transformation from fly ash diffractogram. XRD pattern of geopolymer shows the presence of many sharp peaks at (2θ) between 11°-60° indicating the formation of geopolymer phase, which has been occurred. The presence of peak particularly at 60° with an increase in the height of the intensity indicates the presence of structural rearrangement of mullite during polymerization.

3.3 FTIR-ATR characterization

The characteristic spectra of geopolymer and flyash is given in Fig. 4a and b respectively. The area of interest is 900 cm^{-1} to 1200 cm^{-1} as this range is indicative of the vibration mode of silica bonds [12]. The peaks between 800–900 cm^{-1} can also be assigned to the stretching vibrations of Al – O and Si – O [13]. The presence of CaCO3 is indicated by the peak at 1443 cm^{-1} [14, 15]. This confirms the presence of calcium along with silicon and aluminium. The peak at 946 cm^{-1} represents the asymmetric stretching of Si–O-Si / Si–O-Al. The vibration at 946 cm^{-1} is shifted to 911 cm^{-1}. Such shift to lower wavenumber is understood as the formation of geopolymer [16]. The shift in the Si–O-Si and Al-O bands towards lower wavenumber indicates that geopolymerization has occurred through partial replacement of silica species by alumina, resulting in a change in the chemical bonds [12, 17]. The symmetrical stretching of Si–O-Si and Al–O–Si, was presented at about 672 cm^{-1} in the geopolymer indicating the formation of an alkaline aluminosilicate network [18], a peak appeared at 1737 $cm^{-}1$ can have attributed to C=O stretching vibration (2000) [11].

3.4 SEM characterisation

Images of SEM are as shown in Fig. 5a, b, c. From the Fig. 5a it is observed that the flyash is coarse with spherical shape and some with sharp edges. Geopolymer image (Fig. 5b) is observed with amorphous, dense and gel like structure. Pores were observed in between the amorphous could be due to the extra liquid trapped in the spaces were evaporated after polymerisation leading to the formation of voids. Unreacted flyash and more micro cracks were also observed in image 5b. Micro cracks indicate the brittleness of the material. Wood geopolymer composite board was observed with dense condensed structure. Mustafa Al Bakri et al., (2012) [19] investigated the curing of the samples at elevated temperature and had indicated compact microstructures in SEM.

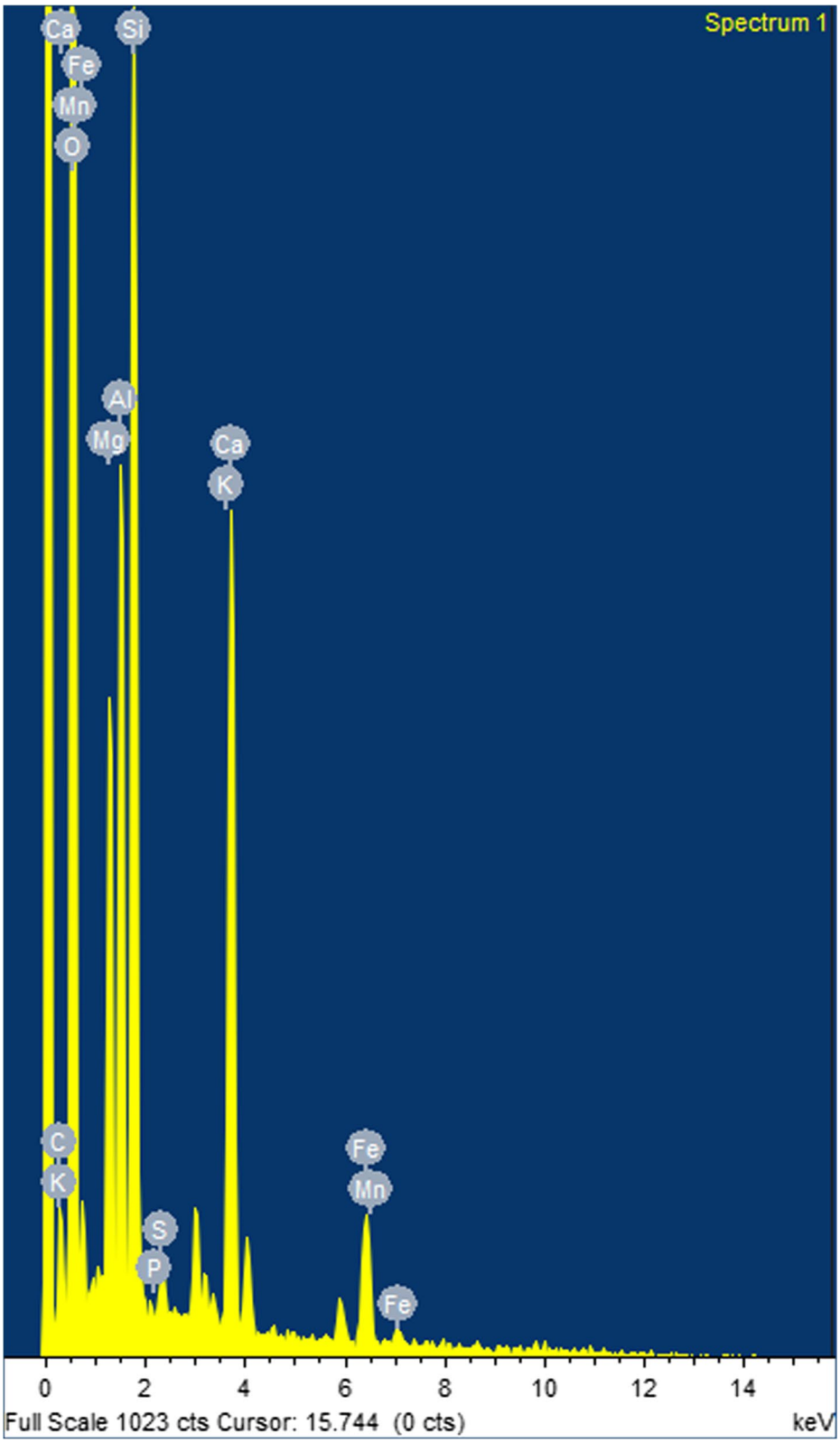
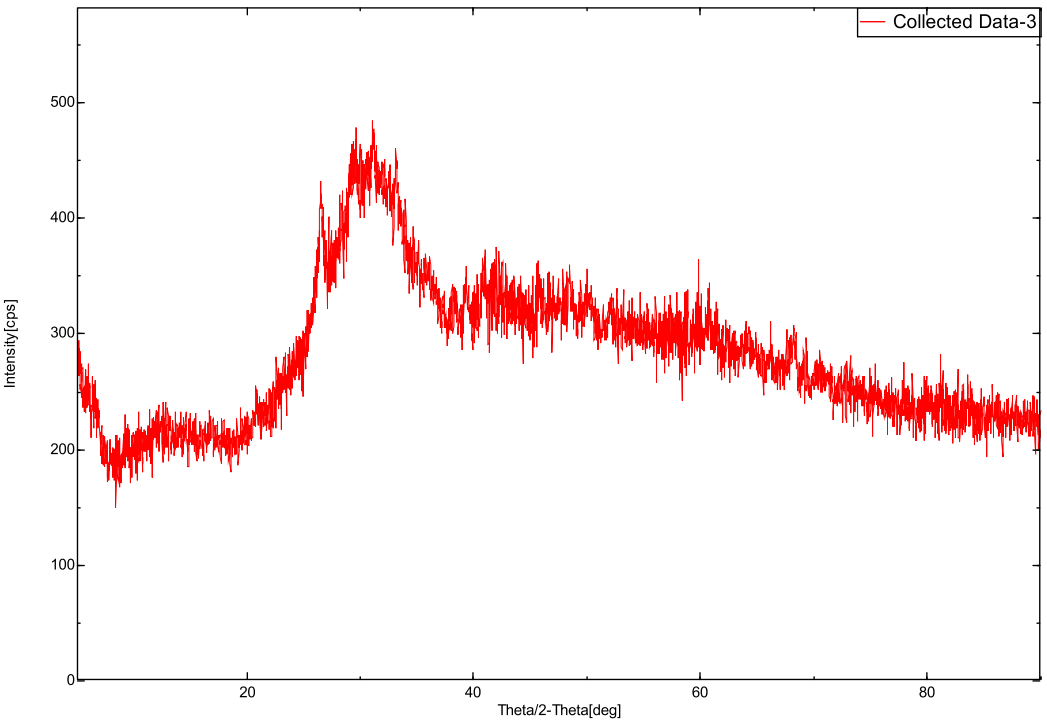
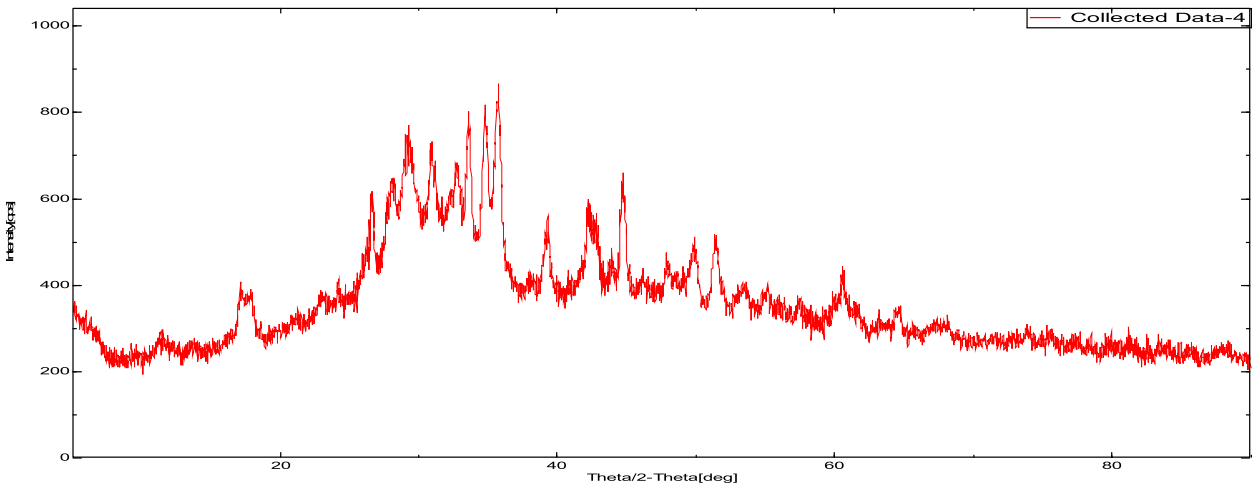


Fig. 2 EDAX graph showing elements in flyash



a XRD of flyash



b XRD of geopolymer

Fig. 3 **a** XRD of flyash. **b** XRD of geopolymer

Table 2 Representing peaks of XRD graph of flyash at 2theta

2-theta(°)	ESD	d(Å.)	Height(cps)
26.3509	0.0466378	3.37947	163.14
60.7661	0.316629	1.52299	12.45

3.5 Effect of wood particle and flyash ratio on properties of wood geopolymer composites

Different weight ration percentage of wood particles to flyash (23/77), (37/62), (44/55) (50/50) (57/43) were studied to understand the effect of wood particles to flyash weight ratio on the properties of wood geopolymer

Table 3 Representing peaks of XRD graph of geopolymer at 2theta

2-theta(°)	ESD	d(Å.)	Height(cps)
11.5118	0.060584	7.68065	29.88
29.2821	0.029578	3.04751	115.11
30.8048	0.010628	2.90025	88.94
32.782	0.037738	2.7297	69.87
33.5941	0.016737	2.66554	159.15
34.7692	0.016863	2.5781	191.97
35.6985	0.01478	2.51309	248.49
39.2307	0.016993	2.29457	92.46
42.1995	0.030747	2.13975	110.7
44.7038	0.007769	2.02553	164.27
49.8778	0.018294	1.82686	65.3
51.3523	0.042774	1.77781	87.68
60.5392	0.102327	1.52815	49.79

composite. Analysis of variance of different ratios of wood particles to flyash on physical and mechanical properties has shown significant effect at $P<0.05$ in Table 4. Values of water absorption and thickness swelling are depicted in Fig. 7.

Density of wood particles and bulk density of flyash were 500 kg/m^{3}and 800 kg/m^3 respectively. Figure 6 displays the density of wood geopolymer composites wherein std1 and std2 indicates values prescribed by Specification in cement bonded particle board and wood particle board respectively. All the boards manufactured were in the range of 900 to 1200 kg/m3 except sample P. Hence all the boards are considered as high density boards except sample Z containing 57 percent wood particle is medium density composite. Density of sample P was increased to 1580 kg/m^3 with the increase in total mass of the ingredient. Figure 6 shows that the increase

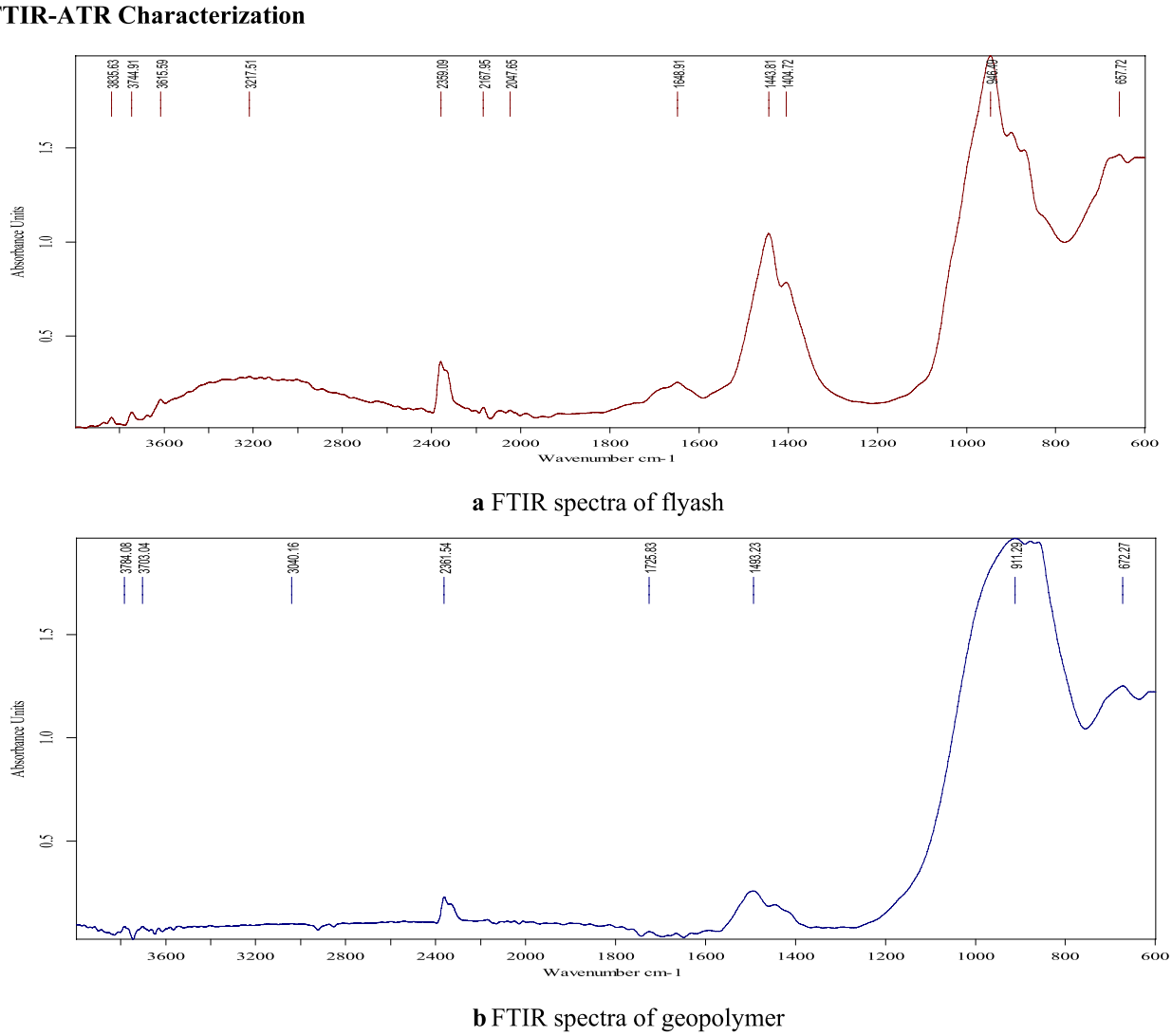
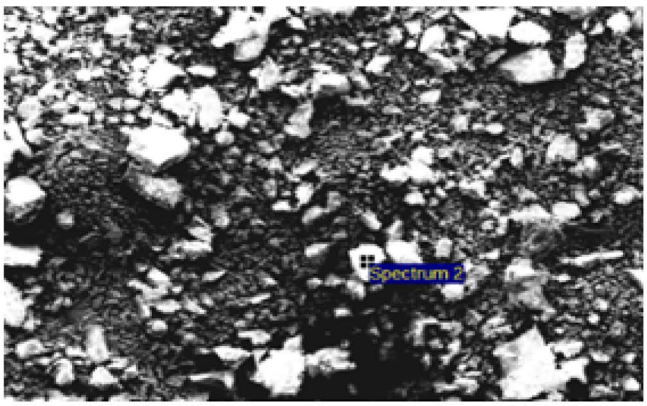
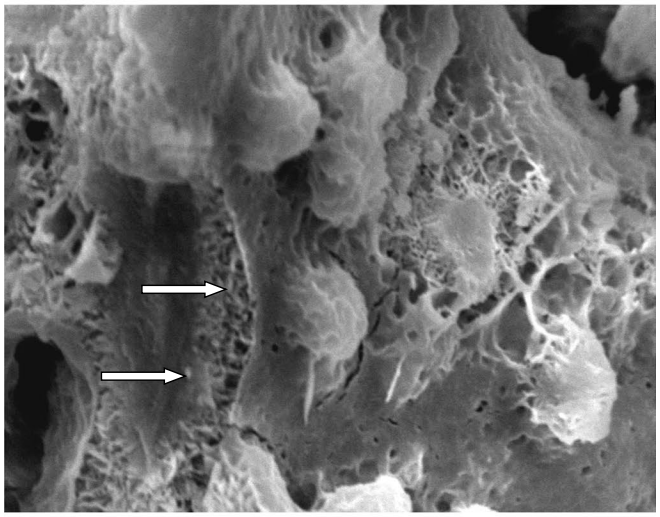


Fig. 4 **a** FTIR spectra of flyash. **b** FTIR spectra of geopolymer

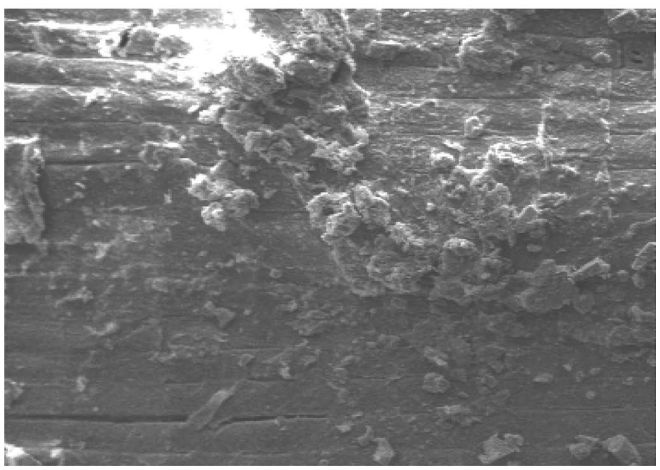
SEM Characterisation:



a SEM images of flyash



b SEM image geopolymer



c SEM image wood geopolymer composite

Fig. 5 **a** SEM images of flyash. **b** SEM image geopolymer. **c** SEM image wood geopolymer composite

Table 4 Analysis of variance for the effect of different ratios of wood particles to fly ash on physical and mechanical properties

Property	Density	WA	TS	MOE	MOR	IB
P values	1.44e-21	8.36e-34 6	6.75e-44	1.81e-27	2.12e-27	4.4e-15
Significance level	**	**	**	**	**	**

ns at $p < 0.05$

** significantly different at $p < 0.05$

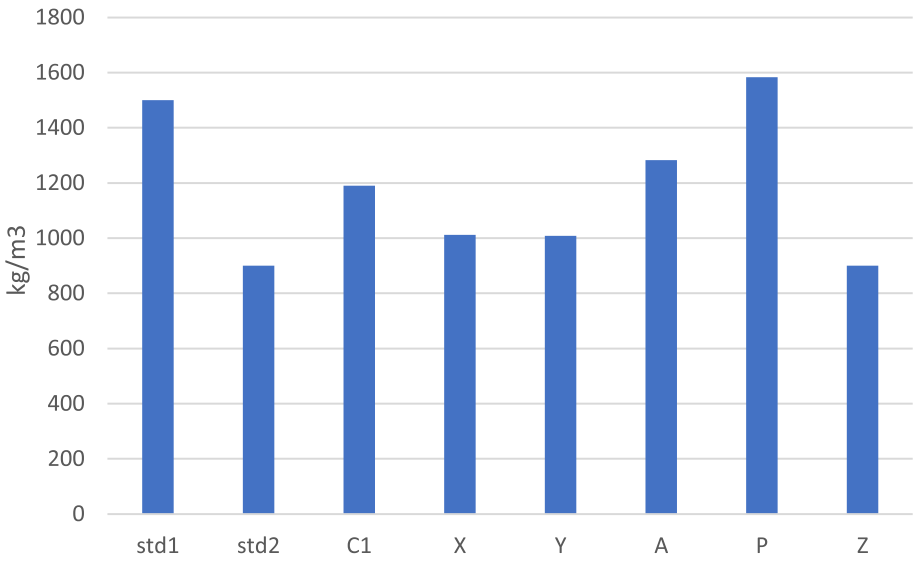


Fig. 6 Density of wood geo polymer composite

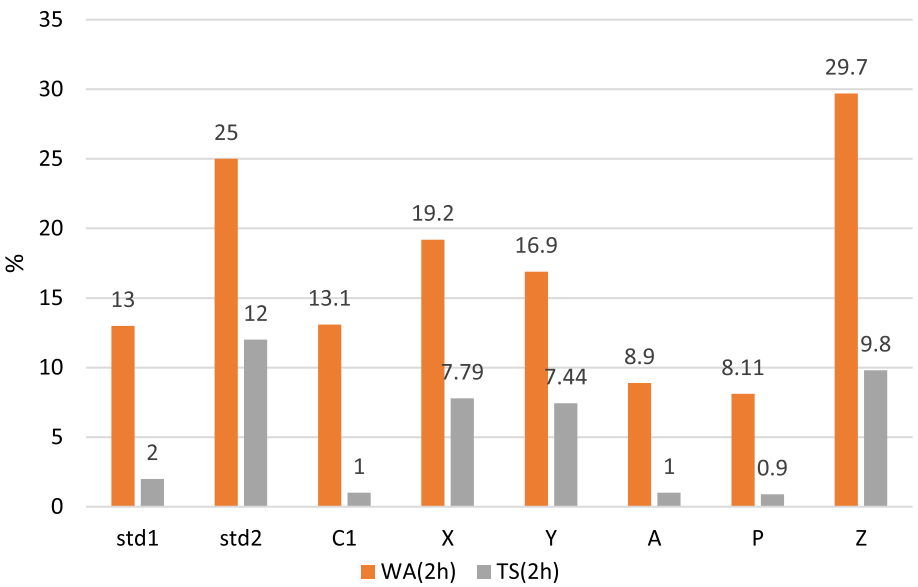


Fig. 7 Water absorption and thickness swelling properties of composites

in the percentage of wood particles, density of the boards found to be slightly decreased.

Figure 7 shows the effect of wood particle /flyash ratio on sorption properties of composite. Samples containing 23% wood particles has shown least water absorption of 8% and maximum water absorption of about 30% was observed in the composite containing 57% wood particle. Sarmin (2016) [16] incorporated 10% wood particles

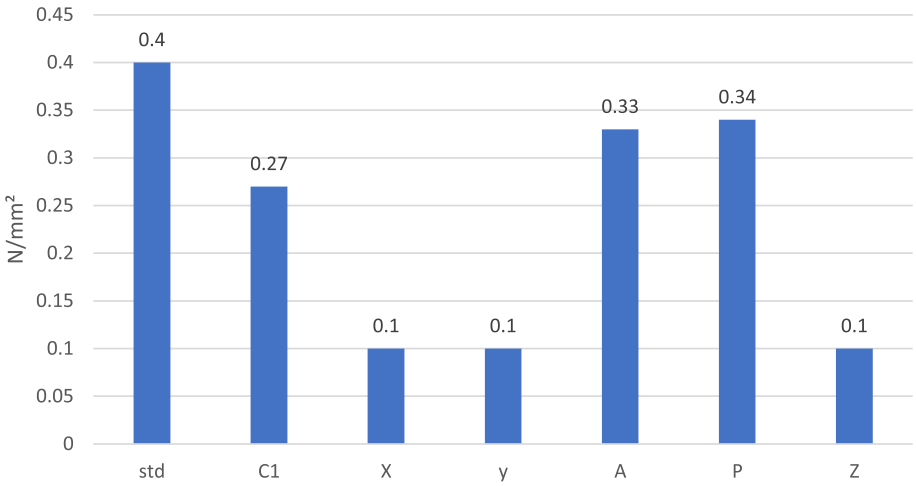


Fig. 8 Internal bond strength properties of Composites

of 3-5 mm in geopolymer binders of density 1550 kg/m3 demonstrated a water absorption of 20%. In the present study water absorption of less than 10% has been observed for the particle size of 1 mm. Sarmin (2016) [16] has revealed that the type of wood aggregates influences on the water absorption and compressive strength properties of the board. More the introduction of wood particles has enhanced the water absorption of the samples. This is obvious as the wood particles by nature are hygroscopic and more the quantity of wood particles has increased the agglomeration and creating voids which has led to the movement of water. Study by Oliyawola 2021 [20] showed the water absorption ranging from 20.33%—40.82% while the thickness swelling ranging from 1.08%,—2.42% for *A. longifolia, A. mearnsii,* and sugarcane bagasse geopolymer boards, respectively with fixed 20% wood particles reinforcement in the composite. And the author concluded in the study that the unreinforced geopolymer boards absorbed less water than the reinforced geopolymers due to the hydrophilic nature of wood particles.

Figure 7 shows the effect of wood particle /flyash ratio on thickness swelling property of composite after 2 h of soaking in water at 25^0 C. Thickness swelling was observed to be minimum of 0.9% in the sample containing highest flyash. With the increase in wood particles, thickness swelling increased to a maximum of 9.8%. According to the Indian standard wood particle board IS: 3087 of grade -2 requires water absorption of maximum 25% and thickness swelling of 12% after 2 h of soaking., All the boards satisfied sorption properties for wood geopolymer composite as per the wood particle board standard except sample containing 57% wood particles. Wood geopolymer composite consisting of 23% wood particles

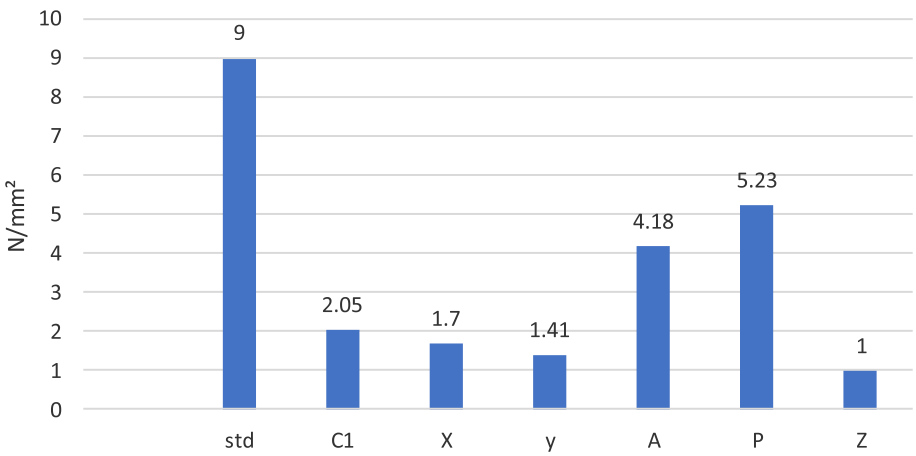


Fig. 9 Modulus of rupture properties of composites

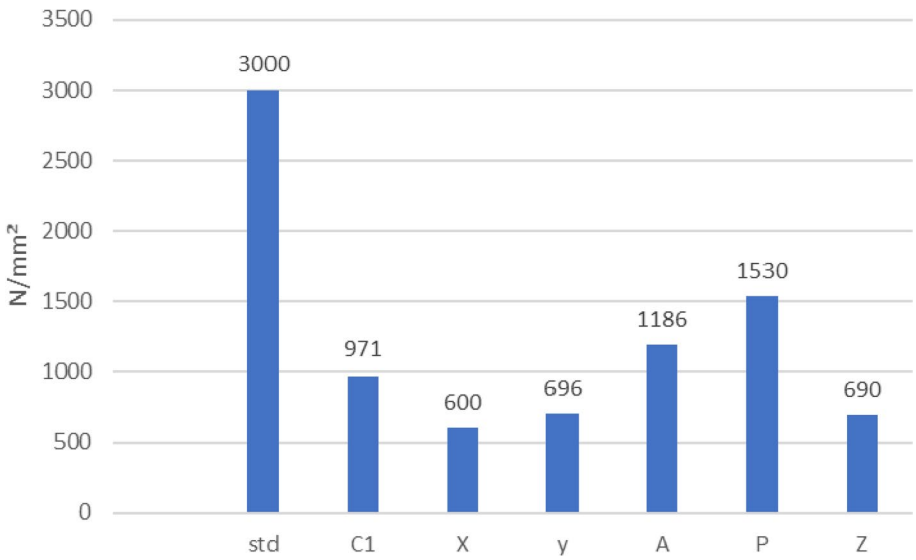


Fig. 10 Modulus of elasticity properties of composites

has satisfied Grade—1 category of Indian standard being less than 10% water absorption and 0.9% thickness swelling. This is evident that the water was only absorbed into the open cracks and the matrix was compact enough to uphold the dimensional integrity of the boards.

Internal bond strength indicates the bonding ability of wood particles with geo matrix. Figure 8 indicates the internal bond strength of composite. The sample with 23 percentage wood particles incorporated has shown highest internal bond strength of 0.3 N/mm^2 indicating a good interaction of geopolymer with wood particles. Increasing the wood particle ratio in composites from 23 to 57%, internal bond strength decreased to 0.1%. Samples showed very low internal bond strength in case of samples containing more than 44% of wood particles. The poor adhesion between the geopolymer and the wood particles or the lack of bonding between the wood and geopolymer in higher percentage of wood particles incorporation lead to the deterioration of properties. The failure of wood particle interaction with the geopolymer in higher percentage of wood may be due to the aggregation of geopolymer and wood particles with in themselves. The presence of alkaline activating solution during the entire curing process would have also deteriorate the wood structure and have negatively influenced the properties. According to Soutsos et al., (2016), [21] increasing the alkali dosage affected the properties of fly ash-based geopolymers until an optimum value of 12.5%, beyond, which the strength decreased. However, in the present study alkali percentage within the optimum level is used. The study conducted by Ye et al. [22] reported that higher lignin content of the species causes reduction in the strength of metakaolin-based geopolyner based composite. Species used in the study *gravelia robusta*, which generally contains approximately 23–26% lignin and the alkali solution might have caused the migration of excess alkali anions into the fibre bundles leading to degradation of the holocellulose. According to the Indian standard for cement bonded particle board, minimum requirement of internal bond strength requirement is 0.4 N/mm^2. Only the lowest wood particle (23%) incorporated geopolymer composite has found values close to the requirement.

Sample containing lesser percentage of wood particles has shown high mechanical properties comparatively. In general, geopolymer being an inorganic material is brittle by nature and addition of small quantity of wood particles may have reduced the toughness of brittle matrix of geopolymer with reduced cracking as observed in SEM (Fig. 5c). The presence of cracks (Fig. 5b) would create stress and doesn't carry the load effectively. Either the wood particles have reduced the cracks and or have delayed the process of formation of cracks at the micro level, which has positively influenced on the properties of the board. Zhang et al., 2014 [23] reported that the addition of carbon fibres prevented crack formation and propagation, and enhanced bending strength under high temperature. Mustafa Al Bakri et al., (2012) [19] investigated the possibility of making foam concrete using Class C fly ash based geopolymer samples cured at 60 °C had maximum compressive strength which was supported by SEM analysis which indicated compact microstructures. It was concluded that increase in curing temperature accelerated the geopolymerization process, which led to a denser matrix. In this study increase in the wood particles above 23% in the wood geopolymer composite have

reduced the mechanical properties of the boards. Figures 9 and 10 shows the highest MOR of 5.23 N/mm^2 with MOE of 1530 N/mm^2 was observed for the sample configuration (P) containing 23% wood particles and 77% flyash with a density of 1583 kg/m^3. However same composition sample with a density of 1283 kg/m3 has shown MOR of 4.18 N/mm^2 and MOE of 1200 N/mm^2. Increase in overall density of the composite have enhanced the mechanical properties of wood geopolymer composite. But the high density composite was very heavy to work. Duan et al. [7] incorporated up to 20% wood particles in geopolymer binders in the form of sawdust and reported that sawdust retains positive effect on compressive strength of geopolymer, especially when more than 10% of is incorporated in geopolymer. Chen et al., 2014 [5] reported that the work of incorporation of 2 to 20% sorghum fibre content in geopolymer-bonded composites showed decreased in properties as the sorghum fibre content increased. The optimum content was found to be 2% of geopolymer precursor. The board made using 23% wood particle had comparable MOR properties with fly ash and metakolin based geopolymer reinforced with 20% treated particles of acacia merantis and higher than bagasse incorporated geopolymer composite reported by Olayiwola (2021) [21]. The MOE and MOR of sugarcane bagasse of 20% incorporated geopolymer composite made using flyash and metakolin of Olayiwola (2021) [21] has 1.68 – 4.95 MPa. The present study shows the MOE in par with properties of MOE of treated bagasse with flyash metakaolin based geopolymer composite of Ojiyan 2021. Within the experimental conditions in this study maximum value was obtained only with 23% wood particle incorporated geopolymer composite.

4 Conclusion

Flyash is used as precursor with alkaline activator in the ratio 1:2.5 for the geopolymer formation. The formation of geopolymer is observed by the movement of peak to lower wavenumber number in FTIR. Wood geopolymer composite was prepared in the varied ratio of wood particles is to flyash (23:77), (37:62), (44:55), (50:50) and (57:43). SEM showed the reduction of cracks due to the addition of wood particle. It is concluded from the study that increase in the wood particle ratio has reduced the density of the boards. Wood geopolymer composite containing 50% wood particles with 50% flyash has satisfied sorption properties for wood geopolymer composite as per the BIS standard of Grade-2 wood particle board (IS:3087) and cement bonded particle board (IS: 14276). Wood geopolymer composite consisting of 23% wood particles has satisfied Grade -1 category of Indian standard in sorption properties showing 8% water absorption and 0.9% thickness swelling. The study concludes that increase in the wood particles above 23% in the wood geopolymer composite have reduced the mechanical properties of the boards. The highest MOR of 5.23 N/mm^2 with MOE of 1530 N/mm^2 was observed for the sample configuration containing 23% wood particles and 77% flyash with a density of 1583 kg/m^3.

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Authors' contributions
Dr Mamatha.B.S, PI of the project, characterisation of flyash, preparation of geopolymer, characterisation of it.and optimisation of manufacturing of composite. Ms.sujatha D, chemical engineer contributed in designing the factor of manufacturing of composites. Mr.uday D.N, mechanical engineering contributed in process optimisation of composites, designing of machines relevant to the manufacture of composite. Mr.Kiran m.C: Evaluated the properties of composites and statistical analysis.

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Availability of data and materials
In this article detailing where the data supporting the findings can be found in tables and figures.

Declarations

Competing interests
No competing interest.

Author details
[1]Scientist E., Institute of Wood Science and Technology, GoI, Bangalore, India.
[2]Scientist F., Institute of Wood Science and Technology, GoI, Bangalore, India.

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