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Research Article

Development of low formaldehyde emitting particle board by nano particle reinforcement

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Abstract
Nanoscience and nanotechnology offer a plethora of possibilities for improving the qualities of wood composites. The present study aimed to use nanotechnology to develop low formaldehyde emitting particle board as ecologically acceptable composites. Conventional urea Formaldehyde resins were prepared by the percentage of second urea at 10%. Nano-wollastonite, silica and montomorillonite with the size range of 25-100 nm were applied at 0.5-2.0% based on the weight of resin. The nano-reinforced resins were admixed with suitable hardener and the panels were made. Formaldehyde emission reduction in wood panel products is critical and it can be partially controlled by using resin modification. The effectiveness of nanoparticle addition to reducing formaldehyde emission from wood particle board was examined by the perforator method as per IS 13745 (1993). Physical and Mechanical properties were evaluated according to IS 3087 (2005). The result indicated distinctly lower water absorption and thickness swelling of panels produced with 1.5 %, 1.5 % and 2.0 % nano silica, nano montomorillinite and nano wollastonite respectively. The results showed that static bending of the produced composite varied from 21.07 to 28.86 N/mm^2 of MOR and from 2246 - 3353 N/mm^2 of MOE; while internal bond strength (IB) varied from 0.35 to 0.58 N/mm^2. As per IS 3087 (2005) requirements, 1.5 % nano silica and montomorillonite and 2.0 % nano wollastonite mechanically modified urea formaldehyde based agro composites gave the best results for grade II particle boards. The study concluded that nanoparticle addition reduces the formaldehyde content in the panel without affecting the strength properties.

Keywords: Nanoparticle, Particle board, Urea formaldehyde resin, Mechanical properties

INTRODUCTION

The wood panel industry depends on polycondensed thermosetting resins, of which urea formaldehyde is one of the most significant (Ciraci, 2005; and Lei *et al.*, 2008). Particle board panels are created from wood particles and are a renewable bio resource. Particle board panels are commonly used in furniture and decoration, whereas plywood panels are mostly employed for structural purposes (Azambuja *et al.* 2018; Hameed *et al*. 2019; Hernández *et al*. 2020; Iždinský *et al*. 2020, Farah *et al.* 2021)

Formaldehyde emission is an important feature to consider when purchasing wood panels for home usage. Formaldehyde has a recognised harmful effect on human health (Roffael, 2006; Salthammer *et al.*, 2010 and Anonymous, 2012). Wood composite panels emit formaldehyde as a result of their formaldehyde-based resin content, which is a disadvantage in many applications. The current glue industry's principal goal is to meet both of these needs by developing effective urea formaldehyde resin with very low, if not nil, formaldehyde emissions. Cademartori *et al.*, (2019) added small percentages of aluminium oxide nanoparticles into UF resin rand investigated thermo-mechanical properties of the composites. They reported that aluminium oxide nanoparticles were effective to reduce the formaldehyde emission (14%) from MDF based on the results of the desiccator test. pMDI may be regarded as the most obvious formaldehyde-free adhesive candidate (Solt *et al*. 2019).

For wood composite materials, nanoscience and nanotechnology offer several benefits. The use of nanotechnology in the production of particle board panels is critical in addressing the formaldehyde emission problem (Johnes *et al.*, 2005; and Roughley, 2005). Throughout the last two decades, nanotechnology has been used to improve the properties of a variety of materials, including solid wood and wood composite panels (Dukarska, 2013; Gallo *et al.,* 2013; Hassani *et al.,* 2019; Esmailpour *et al.,* 2019; and Esmailpour *et al.,* 2020). Large particles of the same substance appear to cause a series of distinct material characteristics changes that nanoparticles do not (Li, 2012). A green binder was developed with oxidized corn-starch (OCS) and urea (U) for wood-based panel production. Nano-TiO_2 modified the obtained adhesive. Developed OCS – U based adhesive can be used with traditional melamine urea formaldehyde resin as a hybrid adhesive system for producing particleboards with low formaldehyde content (Oktay *et al*. 2021).

Nanomaterials contain a lot of mechanical qualities and unique properties that aren't seen in micromaterials. Thus they have a lot of future potentials (Haghighi-Poshtiri, 2013; Taghiyari, 2013 a; Taghiyari and Nouri, 2015; Taghiyari *et al.*, 2016a; Taghiyari *et al.*, 2016b; Taghiyari *et al.*, 2018; and Reinprecht *et al.* 2018). Valle *et al*. (2021) studied the influence of SiO_2 nanoparticles on the physical and mechanical properties of wood particleboard. They showed that panels produced with the nanoparticles 42% reduction in thickness swelling of the panel.

However, more research into nanomaterials is required. To find potential technical applications and industrial productions, we must first establish the mechanical properties of distinct nanomaterials. Some natural scavengers such as chestnut shell flour, phenolated kraft lignins, tannins extractives, soy flour (Taghiyari *et al.* 2020), melamine, polyvinyl alcohol, and adipic acid dihydrazide (Liu *et al.* 2020), alizarin red sulfonate, alizarin yellow-GG, and chromotropic acid decreased the formaldehyde emission from wood-based panels produced with UF resin (Kord *et al.* 2021). There is only limited research on the formaldehyde emissions of particle board enhanced with nanomaterials under various settings (Moubarik *et al.,* 2010; Candan and Akbulut, 2012; Taghiyari *et al.,* 2013; Taghiyari *et al.*, 2013b; Karmi *et al.*, 2013; Candan and Akbulut, 2015; Poshitril 2015; Waheed *et al.* 2020). The study aimed to create an environmentally friendly particle board with minimal formaldehyde emissions and to investigate the impact of nanoparticle loading on thermosetting resins.

MATERIALS AND METHODS

Materials

Poplar particles were taken from our headoffice IPIRTI, Bangalore. Industrial grade urea and formaldehyde were purchased from Oswal Scientific Pvt. Ltd, Chandigarh. Wollastonite (Kemolite KFB-1010) was provided by M/s Wolkem India Limited, Rajasthan, India, for project work as a free sample. Silica and montomorillonite was purchased from Sigma Aldrich.

Methodology:

Preparation of nanoparticle

Commercially obtained wollastonite (KFB-1010), silica and montomorillonite (K10) powder particles with an average particle size of about 8 µm, 0.03 µm, around 6-13µm respectively were used as starting materials. Properties of bulk particles are given in Table 1. A high-energy planetary ball mill machine was used for ball milling (Retsch PM 100). Zirconium balls with a diameter of 10 mm were confined in a bowl as the milling container. Hardened chromium steels were used to make both the ball and the bowl. The ball to powder weight ratio was preserved at 4:1 in all runs, and the bowl rotation speed was around 300 rpm. The speed was selected as per instrument and materials. Milling was done in an open environment at ambient temperature (Fig.1). XRD was used to determine the structure of the samples. This software was used for calculating the crystallite size and internal strain of the sample by the following equation (Williamson and Hall, 1953).

$$d = \frac{K \times \lambda}{\beta \times \cos\theta} \qquad \text{--------Eq. 1}$$

Table 1. Properties of bulk particles

S.N.	Properties	Wollastonite (Kemolite KFB-1010)	Silica	Montomorillonite (K10)
1	Chemical properties(%)	Metasilcate 94.78 $CaSiO_3$ (CaO+ SiO_2) 0.78 R_2O_3(Fe_2O_3 + Al_2O_3)	Silicon= 46.83 Oxygen=53.3	Phylosilcate SiO_2 =43.77 Al_2O_3=18 CaO=1.02 Na_2O=1.03 H_2O=35.6
2	Physical properties			
	Brightness	85.10	-	-
	Density	490kg/m^3	02.3lb/cu.ft	300-370kg/m^3
	Particle size	3.88µm	0.2-0.3 µm	6-13µm
	Moisture content	0.04%	-	-

Fig. 1. *Preparation of nano particles.*

$\varepsilon = \beta / 4 \tan \theta$ ---------Eq. 2

Where θ is the Bragg diffraction angle, d is the crystallite size, ϵ is the average internal strain, λ is the wavelength of the radiation used, β is structural broadening, which is the difference in integral profite width between the standard and sample, and K is the Scherrer Constant (0.89-0.91). Intergral widh gives an evaluation that is independent of the distribution in size and shape. Peak width is defined by integral breadth. K can vary with the morphology of the crystalline domains.

Synthesis of urea-formaldehyde resin

Conventional urea-formaldehyde resin was employed with a molar ratio of urea-formaldehyde of 1:2 (mole ratio or weight ratio of urea formaldehyde= 1:2) for the manufacturing of particle board. To ensure complete synthesis of methyl urea, the reactants are allowed to react at pH 8.0 for 2 hours at 90± 2^0C under reflex. The reaction was then completed by adding taces of dilute acetic acid (4.5-5) leading to the formation of urea-formaldehyde polymer. The pH was adjusted to 7.5-8 and the remaining urea was added to reduce the formaldehyde concentration when the desired viscosity is achieved (flow time in B4 flow cup 20-25 sec at ambient temperature). After then, the resin was allowed to cool to ambient temperature.

The requirement for adding second urea was to keep a specified quantity of free urea in the resin system to mop up free formaldehyde that may be present at the conclusion of the preparation and to mop up free formaldehyde generated during particle board hot pressing. All attempts to add second urea to the particle board resulted in the removal of a significant amount of free formaldehyde. Table 2 lists the qualities of resin.

Table 2. Properties of resin

S.N.	Properties	UF
1	Flow time of Resin in B4 flow cup (Sec)	20-22
2	Gelation time at 100^0C (sec)	73
3	pH of the resin	8.25
4	Solid content (%)	50.53
5	Water tolerance	1:3-4

Method of adhesive mixing

A known weight of wood particles was obtained. Three-layer particle boards were made with 8% solid resin on the weight of oven-dried core particles and 12% solid resin on the weight of face particles. Resin was mixed with various percentages of micro particles (0.5-2.0%). The dispersion of nanoparticles in the Urea-formaldehyde resin was done by mechanical mixing. The resin was admixed with the required quantity of hardener on the basis of the solid content of resin. The adhesive was slowly added to the wood particles and mixed uniform so as to distribute the adhesive to all the particles. During mixing resin with the particles, the entire quantity of particle was taken in a tray and the resin was slowly poured on the particles. The resin may be added batch-wise and mixing continued by hand. The process of mixing by hand is continued until uniform mixed material is obtained. The adhesive formulation for manufacturing particle board is given in Table 3. The resin quantity was calculated as per literature (Razali *et al*., 2012).

Mat formation

In the present case, mat formation was done manually. Various stages of mat formation are shown in Fig 2.

Table 3. Adhesive formulation for particle board

S.N.	Particulars	Resin	
		Face	Core
1	Particles	320 gm	480 gm
2	Resin required	85 gm	85 gm
3	Nano particles (wollastonite, Silica and montomorilonite)	0.5-2.0% of resin	0.5-2.0% of resin
4	Wax Emulsion 1%	0.85 gm	0.85 gm
5	Scavenger 2%	1.7 gm	1.7 gm
6	Liq Ammonia	1 ml	1 ml
7	Hardener water mixed with hardener	0.34 gm 2.52 gm	0.51 gm 2 gm

Three mm thick aluminium caul plates of required board dimension with 10 % excess in margin was taken. A square wooden frame with dimensions equal to that of the aluminium caul plates. BOPP paper was placed over the aluminium caul plate, followed by the wooden frame. Glued particles are taken inside the frame and spread uniformly by hand. The lid is placed over the particles within the frame and pressed hard to compact the particles, as far as possible. By keeping the lid in place, the frame was removed slowly without affecting the mat. The lid is then removed. A BOPP paper was placed over the mat and finally covered with a aluminium caul plate. Aluminium rods of required thickness (thickness of the board to be made) were placed on two-sided of the furnish formed mat. The assembly was ready for hot pressing. The pre-pressed mat assembly was then inserted into a 350 mm X 350 mm hot press, where the platens were kept at a temperature of 160 to 50 degrees Celsius. Supporting rods to control the thickness to 12 mm were placed on either end of the assembly. A pressure of 25 kg/cm^2 for compression cycle for 6 minutes both the resin system followed by curing cycle of 12 kg/cm^2 for about 6 minutes curing time was employed for 12 mm thick particle board.

The pressure was initially increased to get a high surface density on the board. After the time was up, the pressure was reduced to zero for a few seconds to release the steam that had built up on the boards, and the final result was taken from the hot press. After being removed, the boards were piled on a level platform to achieve moisture equilibrium before being trimmed to size. Fig. 2 shows the end output of particle composites.

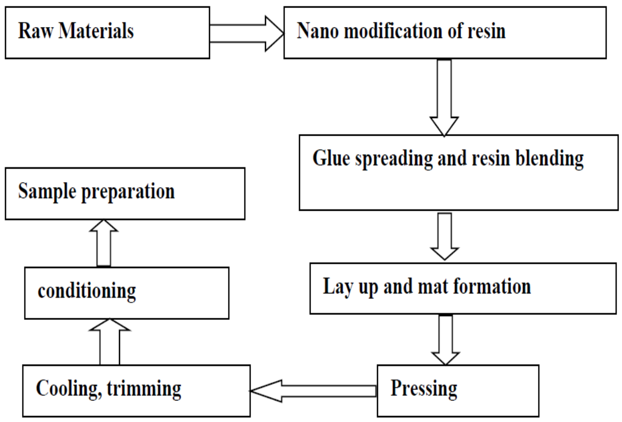

Fig. 2. *Particle board manufacturing process.*

Method for the determination of Formaldehyde Emission Content

The formaldehyde content emission was determined by Perforator method as per IS 13745:1993 “Method for determination of formaldehyde content is particle board by extraction method” (Table 5). The method involved boiling the specimen in toluene, collecting the driven off formaldehyde in water, and analysing it using the Iodometric method. The formaldehyde content/ emitted is obtained by the formula given:

$$= \frac{3.0\,(V_0 - V_1)\,(100 + H)}{M} \qquad \text{……………Eq. 3}$$

= ‘x’ mg/100 gm of oven dry board

V_0 is the consumption in ml of 0.010 mol/l thiosulphate solution for the blank test

V_1 is the consumption in ml of 0.010 mol/l thiosulphate solution for the test

H is the moisture content of the particle board in %

M is the mass in grams of test pieces before the extraction.

RESULTS AND DISCUSSION

Fig.3-8 represents the XRD pattern of wollastonite, silica and montomorilonite powder particles before and after milling. Figures reported the 2 theta angle spectrum 10-70^0 angle range. Based on the XRD pattern, the main peak of 2θ positioned at 30^0, 25.8^0 and 21.6^0 correspond to lattice planes (320), (101), (001) of each ∞ and β of nanowollastonite, nano silica and nano montomorillonite. The XRD patterns of bulk particles showed a very sharp diffraction peak of pure crystalline micro powder. After milling processes, peaks are broadening and decrease in their intensities were observed.

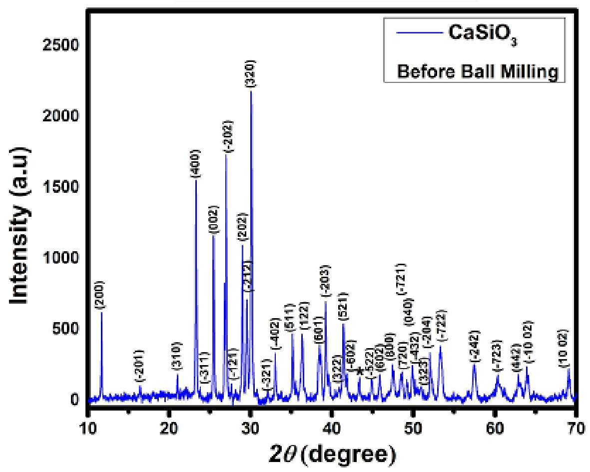

Fig. 3. *XRD image of Bulk wollastonite.*

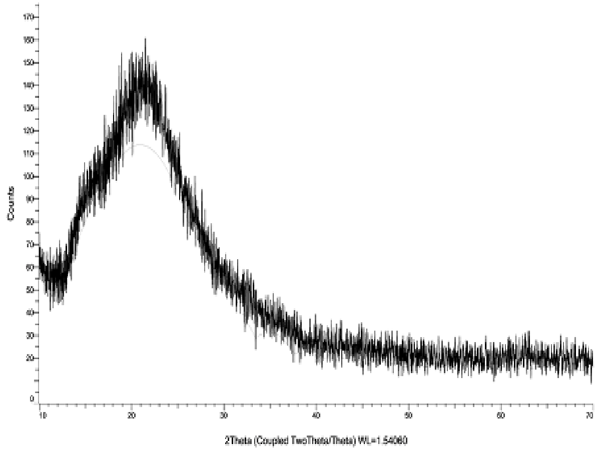

Fig. 4. *XRD image of Bulk SiO_2.*

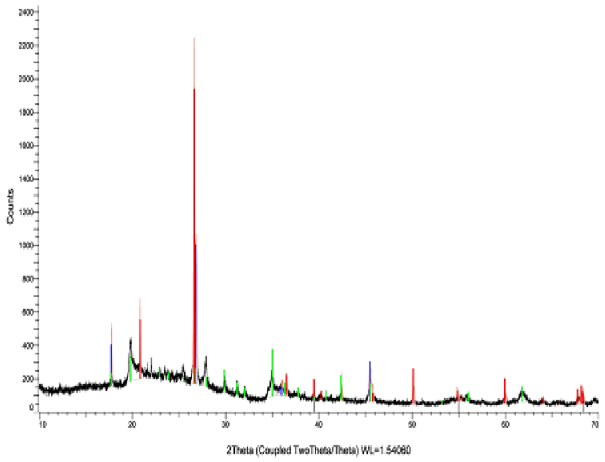

Fig.5. *XRD image of Bulk K10.*

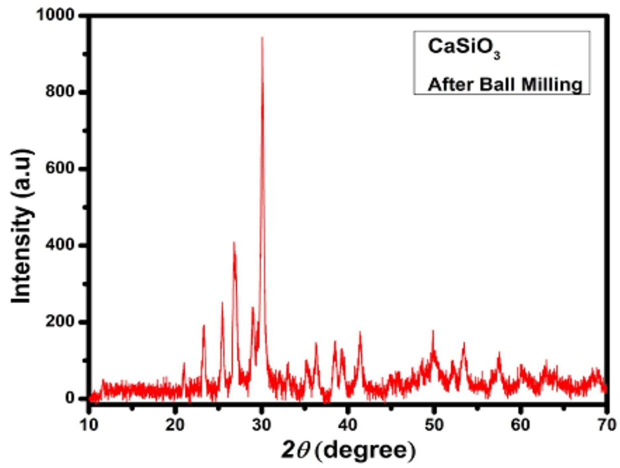

Fig. 6. *XRD image of nano wollastonite.*

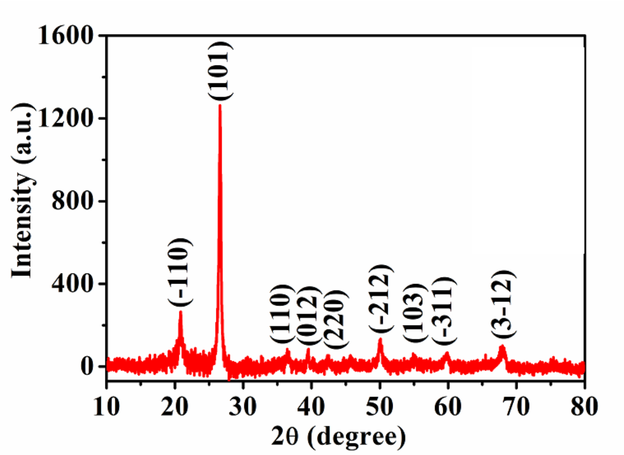

Fig. 7. *XRD image of nano SiO_2.*

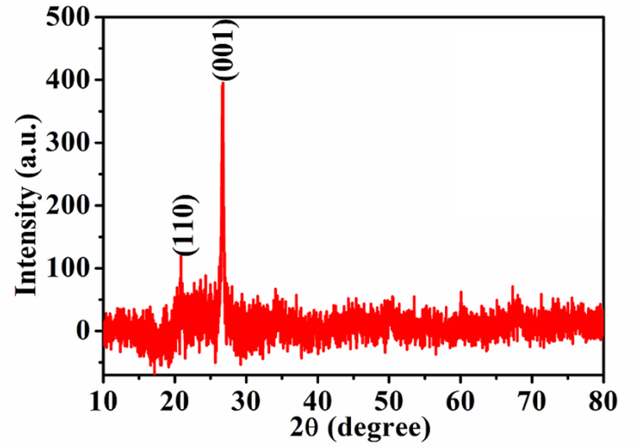

Fig. 8. *XRD image of nano K10.*

This phenomenon (a broadening of the peaks and a reduction in their intensities) was typical of material after milling and was usually related to the existence of small crystalline particles and internal stresses generated by mechanical impacts. Peak broadening could be caused by both a reduction in crystallite size and an increase in lattice strain, as is well known. During ball milling in a planetary ball mill, initial powder particles suffer from very strong high energy impacts attributed to collisions between the ball themselves and the container wall. Large amounts of microstructural and structural changes will occur in the milled powder particles as a result of these powerful impacts. Crystallite size refinement and increased lattice strain result from the

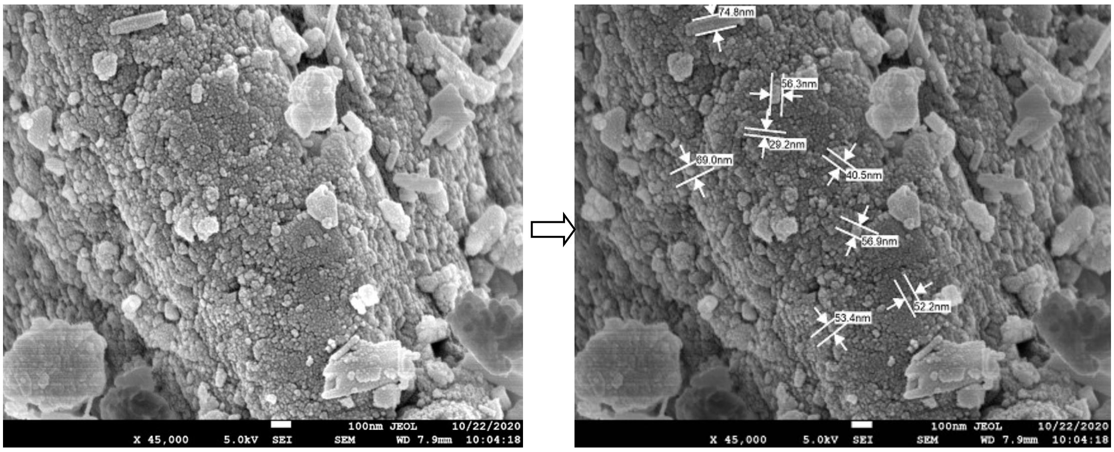

Fig. 9. *FESEM micrographs of nano wollastonite.*

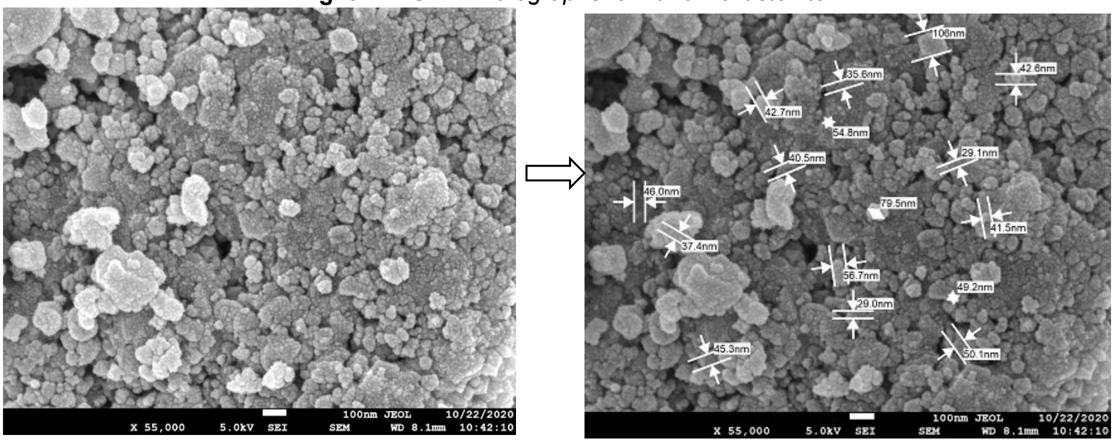

Fig. 10. *FESEM micrographs of nano SiO_2.*

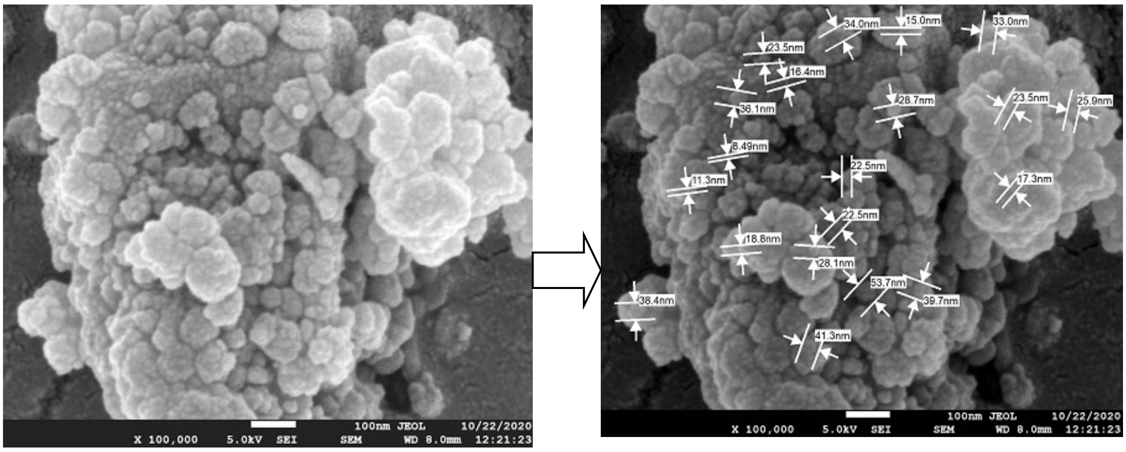

Fig. 11. *FESEM micrographs of nano K10.*

gradual accumulation of faults and their interaction. For the manufacture of nano particle powder particles, the high energy ball milling technique was a very efficient, practically easy, and low-cost process.

Field Emission Scanning Electron Microscope (FESEM)

FESEM was used to view the sample surface. The analysis was done by Central Instrument facility, LPU, Jalandhar. The samples were gold-coated to ensure that the electron beam had sufficient conductivity. Figs. 9-11 show typical FESEM pictures of milled powder. The average particle size of powder particles was around 8 m, 0.03 m, 6-13 m wollastonite, silica, and K10, respectively. The average particle size of nano particles was detected in the range of 25-100 nm in different magnifications when considering the morphologies of the powders milled (Fig. 9-11). The size of particle in SEM micrographs was determined with the help of image analyser software by LPU, shown in Figs. 9-11. The produced nanoparticles were uneven in shape and size, as evidenced by SEM micrographs. Nanopar-

Table 4. Physical and mechanical properties of Particle board

S.No.	Properties	Prescribed value as per IS 3087-(2005) Grade-2	Control UF Resin	$WO_{0.5}$	$WO_{1.0}$	$WO_{1.5}$	$WO_{2.0}$	$SI_{0.5}$	$SI_{1.0}$	$SI_{1.5}$	$SI_{2.0}$	$K_{0.5}$	$K_{1.0}$	$K_{1.5}$	$K_{2.0}$
1.	Density, Kg/m^3	500-900	723	758.7	772.5	774	759.4	752	774	783	756	755	763	774	755
2.	Moisture content , %	5 – 15	9.7	5.94	5.89	5.79	5.86	5.97	6.32	6.42	6.28	6.8	6.59	6.76	6.80
3.	Water Absorption, % After 2 hours of soaking After 24 hours of soaking	Max 40 Max 80	32.7 61.8	31.9 69.96	30.76 65.4	28.56 62.8	26.43 54.7	29.86 61.3	26.53 59.7	23.6 52.8	28.1 59.5	30.7 64.5	29.76 61.75	24.8 54.6	26.75 58.79
4.	Swelling due to general absorption, % (After 2 hours soaking) a) Thickness b) Width c)Length	Max 12 Max 0.5 Max 0.5	6.2 0.29 0.29	6.86 0.3 0.29	5.35 0.29 0.28	4.98 0.26 0.24	4.86 0.24 0.22	6.5 0.28 0.27	5.15 0.26 0.26	4.65 0.21 0.19	5.02 0.24 0.22	6.58 0.32 0.30	5.55 0.28 0.27	4.89 0.23 0.21	5.61 0.25 0.24
5.	Modulus of rupture, N/mm^2 Average Min. Individual	Min. 11 Min 10	24.5 21.6	21.07 19.34	24.79 23.85	24.46 23.76	28.75 28.38	22.6 21.45	26.7 24.61	28.5 25.1 7	21.62 18.63	24.7 2 23.9 5	24.72 25.01	28.86 26.39	26.56 23.48
6.	Modulus of elasticity, N/mm^2 a) Average b) Min. Individual	Min. 2000 Min 1800	3353 3078	2246 2178	2298 2193	2465 2393	2589 2496	2400 2190	2580 2514	2930 2723	2890 2709	2365 1970	2700 2159	2860 2654	2780 2374
7.	Tensile strength perpendicular to surface (IB strength), N/mm^2	Min 0.3	0.35	0.36	0.43	0.47	0.52	0.43	0.48	0.56	0.52	0.39	0.48	0.58	0.43
8.	Swelling in thickness due to Surface Absorption (after 2 hours soaking), %	Max 9	7.6	4.9	3.8	2.06	1.99	4.76	3.95	1.98	2.24	5.1	3.76	2.15	2.56
9.	Screw withdrawal strength, N Face Edge	Min 1250 Min 700	1680 876	2100 915	2245 1071	2875 1471	2950 1860	2375 1286	2590 1480	3086 1905	2976 1876	2285 1121	2456 1425	2986 1891	2860 1786

ticles in the sample had a semi-spherical shape. Particle board panels were cut to size and evaluated for the physical and mechanical properties as per IS 3087 (Table 4).

Water absorption and thickness in swelling

Although particle board panels are commonly utilised in interior applications, they must nonetheless resist water absorption. According to visual inspection, there was no visual difference between the control panels and the panels with nano particle content. When nanoparticles were up to 1.5 percent in the mat in the case of SiO_2 and K10, and 2 percent in the case of wollastonite, water absorption decreased significantly; however, when nanoparticle content was more than this, water absorption increased. The explanation for this can be traced back to the density of different treatments being equal. After 2 and 24 hours, water absorption in nano particle treated panels was lower than in control panels.

Table 4 shows the thickness in swelling values for the nanoparticle panel and the control panel. The results show that the nano material loading amount, nano material type, and the combined effect of these factors considerably reduced the thickness swelling values of the composites after all water soaking periods. The nano particles were used in the composites in this work at a 0.5-2 percent loading level. It was clear that a smaller nano particle loading level had a beneficial effect on thickness swelling properties, whereas a higher loading level had a negative effect. The amount of water that infiltrated through the spaces between particles and the number of swollen fibres was found to have a good association, suggesting a link between the amount of water that infiltrated through the particles and the number of swollen fibres.

Modulus of Rupture (MOR), Modulus of Elasticity (MOE) and Internal Bond (IB) strength properties:

Table 4 shows the results on the mechanical properties of the board as a function of the amount of nano particle added to the urea-formaldehyde resin. As shown in the results, adding a small amount of nanoscopic wollastonite, silica, and K10 to the glue resin (in the range of 0.5-2 percent) generated a considerable increase in the board IB in comparison to the control board. When the amount of nano particle was increased, the IB dropped to a level that was comparable to the control board. The increased wood adhesive contact and removal of gaps on the wood surface by nano particles can be linked to an increase in nano-reinforced boards' bonding strength.

In addition, adding a small amount of nano to a glue resin improved the boards' bending strength MOR and MOE. Table 4 shows the modulus of rupture and modulus of elasticity of the nano reinforced and control boards. All of the nano composites had greater MOR values than the control panel. The MOR of the nano panels increased as the nano material loading level increased from 0.5-1.5 percent Nano SiO_2 and K10 to 2% Wollastonite. The maximum MOR value was found in 1.5 percent reinforced composites.

The modulus of elasticity values of the composites reinforced with nano particles increased as the nanomaterial loading level increased up to 1.5 percent in Nano SiO_2 and K10 and up to 2 percent in Wollastonite, whereas the modulus of elasticity values fell. The reason for increasing mechanical properties due to increasing the crosslink density of urea-formaldehyde resin. Further, the mechanical properties of particles boards depend on the bond between particles and adhesive and the quality of the particles. The bonding of particles- adhesive can be improved by increasing the contact surface area between the matrix and particles.

Formaldehyde emission content

Nanomaterials have distinct properties, such as high chemical activity, physical characteristics as well as a big specific surface area. These characteristics could be leveraged to improve the performance of thermosetting resins and composite materials, opening up new possibilities. Some nanoparticles, however, are prone to aggregation in liquid. Increased nano particle loading levels may have generated aggregation in the nano reinforced resins, lowering the formaldehyde emission value. The particle board panels were made using urea -formaldehyde that had been changed with different nano particles at varying loading levels.

Table 5 shows the formaldehyde data for the nanomaterial reinforced particle board panels and the control panels. UF nanocomposites could effectively decrease the formaldehyde emission of the UF adhesive. The emission was reduced after adding up to 1.5 percent nano Silica and K10 and 2 % wollastonite to the adhesive formaldehyde. However, increasing the level of nano particle loading resulted in more formaldehyde emission. The reason is as follows: firstly, nano particles could adsorb the formaldehyde; secondly, cross-linking network of the UF nanocomposites could prevent the formaldehyde from escaping from the polymer and thirdly, structural stability of the network became stronger and the polymer chain; could not easily be broken to emit formaldehyde (Danyliuk etal. 2020). It could be noted that the formaldehyde emission was least when the nanosilica and nano K10-1.5% and wolaastonite 2.0% were used. The reason for that particles was dispersed in the solution. When the content was high, it was more difficult for the particles to be dispersed in the solution (Cademartori *et al.* 2019; Song *et al.*, 2021). The active group of urea-formaldehyde can react with a group available in nano particle (Lin *et al*., 2006; Roumeli *et al*., 2012).

Table 5. Formaldehyde content in the panels

S.No	Nano Particle p ercentage	Sample Code	Formaldehyde content in mg/100 gm of dry board
1.	UF Resin	UF	8.9
2.	Wollastonite (KFB-1010)		
(i)	0.5	$WO_{0.5}$	6.85
(ii)	1.0	$WO_{1.0}$	5.63
(iii)	1.5	$WO_{1.5}$	4.86
(iv)	2.0	$WO_{2.0}$	3.2
3.	Silica Powder		
(i)	0.5	$SI_{0.5}$	6.1
(ii)	1.0	$SI_{1.0}$	4.05
(iii)	1.5	$SI_{1.5}$	2.15
(iv)	2.0	$SI_{2.0}$	3.82
4.	Montomorilonitre (K10)		
(i)	0.5	$K_{0.5}$	5.9
(ii)	1.0	$K_{1.0}$	4.25
(iii)	1.5	$K_{1.5}$	2.48
(iv)	2.0	$K_{2.0}$	3.9

Conclusion

Converting micronized particles into nano form by mechanical milling with planetary ball mill is a simple and effective method. The use of nanoparticles for UF resin results in significant decrease of formaldehyde release from the produced particle boards. NanoSiO_2, nano montomorillonite, and nano wollastonite were used to reinforce particleboard composites at different loading levels i.e. 0.5-2.0 %. Peaks broadening and decrease in their intensities were observed in nanoparticle XRD image. The average particle size of nanoparticles was detected in the range of 25-100 nm by FESEM.

It was found that the fortification of UF resin with 1.5 % nano silica and nano montomorillonite and 2 % nanowollastonite can be considered as an optimum level. Results showed that optimum level have significantly lower water absorption, thickness swelling, low formaldehyde emission and higher mechanical strength. The density of the prepared particle board was achieved between 750-800 kg/m^3 for dimensions of 0.3 X 0.3 X 0.012 mm. As for modulus of rupture and modulus of elasticity, the highest performance was obtained in the composites reinforced with 1.5 % nano silica and nano montomorillonite and 2 % nanowollastonite. The study found that nanoparticle (1.5 % nano silica and nano montomorillonite and 2 % nanowollastonite) reduced the formaldehyde content in the panel without affecting the strength properties. Thus, it would help in developing low formaldehyde emitting environmentally friendly wood composite panels by nanoparticle modified resin.

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Conflict of interest

The author declare that she has no conflict of interest.

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