EFFECTS OF NANOCOPPER ON PHYSICAL AND MECHANICAL PROPERTIES OF MEDIUM-DENSITY FIBREBOARD

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RANGAVAR H, TAGHIYARI HR & MEHR M. 2013. Effects of nanocopper on physical and mechanical properties of medium-density fibreboard. Effects of copper nanoparticles on physical and mechanical properties of medium-density fibreboards (MDF) were investigated. The size of copper nanoparticles ranged from 20 to 90 nm. Nanocopper was mixed with urea formaldehyde resin at two levels of 60 and 80 mL kg^{-1} based on the dry weight of fibres. The properties of the MDF produced were compared with control specimens. Three hot press times of 5, 6 and 7 min were used. Results showed that the highest physical and mechanical properties were observed in the 5-min 8% nanocopper treatment. Heat transfer property of copper facilitated polymerisation of resin in the core section of the mat and, consequently, improved the properties. Increase in hot press time significantly decreased properties in nanocopper-treated specimens, both in 6 and 8% treatments. The extra heat that was transferred to the surface and core sections resulted in the breaking down of resin bonds. As to the rather similar results of 6 and 8% nanocopper, 5-min nanocopper at 6% concentration may be recommended for use at industrial scale to improve physical and mechanical properties of MDF.

Keywords: Composite board, heat transfer property, metal nanoparticles, MDF

RANGAVAR H, TAGHIYARI HR & MEHR M. 2013. Kesan nanokuprum terhadap ciri-ciri fizikal dan mekanik papan gentian berketumpatan sederhana. Kesan nanokuprum terhadap ciri-ciri fizikal dan mekanik papan gentian berketumpatan sederhana (MDF) dikaji. Saiz nanokuprum yang diguna adalah antara 20 nm hingga 90 nm. Nanokuprum dicampur dengan urea formaldehid pada dua kepekatan iaitu 60 mL kg^{-1} and 80 mL kg^{-1} berdasarkan berat kering gentian. Ciri-ciri fizikal dan mekanik MDF yang dihasilkan dibanding dengan spesimen kawalan. Tempoh penekanan yang diguna ialah 5 min, 6 min dan 7 min. Keputusan menunjukkan bahawa ciri-ciri fizikal dan mekanik yang tertinggi diperhatikan dalam rawatan 8% nanokuprum selama 5 min. Ciri pemindahan haba kuprum membantu proses pempolimeran resin di bahagian teras papan lantas menambah baik ciri-cirinya. Apabila tempoh penekanan panas ditingkatkan, ciri-ciri spesimen yang dirawat dengan nanokuprum 6% dan 8% berkurangan dengan signifikan. Haba yang berlebihan dipindah ke permukaan dan bahagian teras papan lalu mengakibatkan ikatan resin terurai. Memandangkan keputusan yang diperoleh untuk nanokuprum 6% dan 8% hampir sama, pihak industri disyor mengguna nanokuprum 6% pada tempoh penekanan panas selama 5 min untuk menambah baik ciri-ciri fizikal dan mekanik MDF.

INTRODUCTION

Composite boards offer advantages of a homogeneous structure and the use of raw materials without restrictions to the shape and size. In composite-board factories, hot presses are usually considered to be a bottle-neck for nearly all wood-composite manufacturing factories (Doosthoseini 2001). Minimum pressing time of a particleboard primarily depends on heat transfer, which in turn varies with thickness, press temperature, closing rate and mat moisture distribution. When high internal steam pressures are involved, the press times necessary to prevent damage resulting from the release of gases depend on factors such as resin type, density, press temperature, and total moisture content. Based on the low thermal conductivity coefficient of wood, several methods and materials have been used to shorten hot press time, saving time and energy (Taghiyari et al. 2013). Still, except where controlled by high internal pressures or excessive moisture contents, the time

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required to maintain centreline temperatures varies only slightly. Internal pressure on fibres also fluctuates considerably during hot press time, so a mere hot press time report may not be very informative. However, in the case of urea formaldehyde resin, there is limitation of moisture content level due to increase in hot press time which is not economical (Papadopoulos 2006). Furthermore, due to the greater brittleness of urea formaldehyde resin compared with other resins, complete curing of resin would result in improvement of properties (Stockel et al. 2012).

Thermal conductivity of common heat transfer fluids is enhanced when small amounts of metallic and other nanoparticles are dispersed in Cu-H_2O nanofluids (Li et al. 2008, Yu et al. 2010). However, the effect of copper nanoparticle on heat conductivity in composite boards has not been reported. The present study was therefore conducted to evaluate if copper nanoparticles could contribute to heat transfer and improve physical and mechanical properties of medium-density fibreboard (MDF).

MATERIALS AND METHODS

Materials

Wood fibres were procured from Sanaye Choobe Khazar Company in Iran. The fibres comprised a mixture of five species, namely, beech, alder, maple, hornbeam and poplar from neighbouring forests. Boards produced were 16 mm thick; thickness of the boards was controlled by stopper bars. Increase in the density of the boards has been reported to improve board properties (Karlinasari et al. 2012). Thus, in the present study density of all treatments was kept the same (0.75 ± 0.03 g cm^{-3}). Moisture content of the fibre mat before hot pressing was kept constant at 10% in all treatments. Total nominal pressure of plates was 160 bars and the temperature of the plates was fixed at 175 °C. Hot pressing continued for 5, 6 and 7 min in different treatments. Urea formaldehyde resin was obtained from the Sari Resin Manufacturing Company, Iran. Twelve per cent urea formaldehyde resin was used for all treatments based on the dry weight of the fibres. As reported by the supplier, the urea formaldehyde resin has a density of 1.277 g cm^{-3}, solid content 59%, pH 6.8–7.1, viscosity 200–240 cP and gel time at 110 °C of 44–46 s. No hardener was used in the study and five replication boards were made for each treatment.

Nanocopper application

An aqueous nanocopper suspension (400 ppm) was produced using an electrochemical technique in cooperation with Jafr Sorkhe Fajr Co Ltd. The size range of copper nanoparticles was 20–90 nm. This was applied to the fibres in two ways as pretests: (1) directly spraying on the fibres, drying them and then applying the resin on them and (2) adding the nanocopper suspension to the resin before applying it to the fibres. The pH and viscosity of the resin were kept constant for all treatments. For pretests, 80 mL kg^{-1} of nanocopper suspension was used. Boards were hot pressed for 6.5 min.

From the pretests, the best method for mixing nanocopper with the fibres was identified and the final tests were carried out. Nanocopper was used at 60 and 80 mL kg^{-1} wood particle (6 and 8%), on dry wood basis. Therefore, there were three treatments, namely, control, 2–60 and 3–80 mL of nanocopper/kg. Five boards were manufactured for each treatment. Boards were kept in a conditioning room (30 ± 2 °C and 40–43% relative humidity) for 2 weeks before mechanical and physical tests were carried out. Physical and mechanical tests were carried out in accordance with the ISIRI 9044 PB Type P2 (ISIRI 2010) specifications, which is compatible with ASTM D1037-99.

Three-point bending test

Three-points static flexural tests were performed to measure modulus of rupture (MOR) and modulus of elasticity (MOE). Nominal sizes of the specimens were 380 mm × 70 mm × 16 mm, with loading speed of 4 mm min^{-1}. Twenty samples of the same location for each treatment were tested using an INSTRON 4486 test machine with 5 KN capacity.

Physical properties

Thickness swelling and water absorption (2 and 24 hours) were measured using equations

1 and 2 respectively. Nominal dimension of specimens was 200 mm × 100 mm × 16 mm with 20 replications for each treatment. Specimens were weighed to a precision of 0.01 g using a digital scale. Thickness swelling was monitored at five points (one in the centre of the specimen and four at every corner of each specimen) with a 0.01-mm precision digital callipers. The average of the five points is reported in the results.

$$\text{Thickness swelling} = \frac{T_x - T_0}{T_0} \times 100 \qquad (1)$$

where T_x and T_0 = thickness (mm) of the specimen at time x and the initial thickness (mm) respectively. Likewise, the per cent water absorption was calculated as below.

$$\text{Water absorption} = \frac{M_x - M_0}{M_0} \times 100 \qquad (2)$$

where M_x and M_0 = weight (g) of the specimen at time x and dry weight (g) respectively.

Statistical analysis

Statistical analysis was conducted using SAS software program, version 9.1 (2003). One-way analysis of variance (ANOVA) was performed on the data to conclude significant differences at 99% level of confidence. Hierarchical cluster analysis (including dendrogram and using Ward methods with squared Euclidean distance intervals) was carried out by SPSS/16 (2007).

RESULTS AND DISCUSSION

Pretests

Table 1 shows the results of the pretests. Highest mechanical properties as well as lowest physical properties were observed in the mixed nanocopper-resin treatment. The treatment in which nanocopper suspension was first sprayed onto the fibres and dried before the resin was applied on them for hot press showed significant difference. MOE and internal bonding did not show any significant difference between control and nanocopper-sprayed treatments. Cluster analysis showed

Table 1 Physical and mechanical properties of medium-density fibreboard in pretests for three treatments

Property	Control	Nanocopper sprayed on fibres	Nanocopper mixed with resin
MOR (N mm^{-2})	10.8 ± 1.1 (C)	13.5 ± 1.3 (B)	16.7 ± 1.7 (A)
MOE (N mm^{-2})	922 ± 62 (B)	1068 ± 95 (B)	1240 ± 110 (A)
Internal bonding (N mm^{-2})	0.13 ± 0.01 (B)	0.13 ± 0.01 (B)	0.17 ± 0.01 (A)
Thickness swelling (2 hours) (%)	31.8 ± 2.8 (B)	50.3 ± 4.8 (A)	20.7 ± 2.5 (C)
Thickness swelling (24 hours) (%)	34.2 ± 2.6 (B)	53 ± 4.5 (A)	25.6 ± 2.2 (C)
Water absorption (2 hours) (%)	106.7 ± 8.9 (B)	129.8 ± 9.5 (A)	68.7 ± 5.9 (C)
Water absorption (24 hours) (%)	122 ± 7.5 (B)	147.2 ± 11.7 (A)	82.5 ± 7.3 (C)

A, B, C = Duncan groupings; MOR = modulus of rupture, MOE = modulus of elasticity that the mixed nanocopper–resin treatment was clustered differently (Figure 1).

Final tests

Longer hot press times slightly improved physical and mechanical properties in control specimens (Figures 2–8). In nanocopper-treated specimens, however, the best mechanical and physical properties were obtained in shorter hot press time, i.e. 5 min. The highest mechanical properties observed at this press time were in nanocopper 8% treatments (18 N mm^{-2} for MOR, 1792 N mm^{-2} for MOE and 0.36 N mm^{-2} for internal bonding). Increasing hot press time in nanocopper-treated boards decreased mechanical properties significantly.

DISCUSSION

Generally, increase in hot press time significantly improved physical and mechanical properties of control specimens. This shows better polymerisation of resin in the inner part of the mat (the centre of the mat) because of the longer time. Addition of 6 and 8% copper nanoparticles to the resin significantly improved all physical and mechanical properties in 5-min boards. In fact, heat transfer property of nanocopper particles facilitated the transfer of heat to the core parts of the mat and polymerisation was completed much easier and faster. The advantages of this heat transfer property were especially conspicuous in internal bonding values of 5-min boards (Figure 4). In the longer hot press times of 6 and 7 min, there was enough time for heat to be transferred from the surface layers to the core of the mat. Thus, lower differences were observed between the two hot press times. In the 5-min treatment, however, copper nanoparticles were able to demonstrate their effectiveness in heat transfer more evidently. Similar heat transfer property of silver nanoparticles was also reported to improve properties in particleboard (Taghiyari et al. 2011). The lower nanosilver consumption level (100 mL kg^{-1}) showed formation of better polymerisation of resin and, consequently, stronger bonds between wood particles (Taghiyari 2011). Increasing nanosilver consumption level (150 mL kg^{-1}) resulted in depolymerisation of resin (Taghiyari 2011, Taghiyari et al. 2011) and, ultimately, the properties decreased to some extent. Similar effects were observed in the present study; the increase in hot press time drastically showed negative impacts on physical and mechanical properties of nanocopper-treated boards. The negative impact increased as nanocopper consumption level increased from 6 to 7%. The extra heat that was easily transferred to the surface and core parts of the mat in nanocopper-treated boards of 6 and 7 min caused the polymerised resin to break down and, consequently, decreased the properties of the boards. This breaking down of the polymerised resin was also significant between the 6 and 8% nanocopper treatments, both in the 6- and 7-min treatments.

Cluster analysis of the physical and mechanical properties (MOR, MOE, internal bonding, thickness swelling and water absorption) clearly showed that control treatments of 6- and 7-min were closely clustered together and quite differently from 5-min control treatment (Figure 9). Also, control treatment of 5-min was clustered, although not so closely, to the 6 and 8% nanocopper 5-min treatments. This may imply that higher duration of hot press time does not

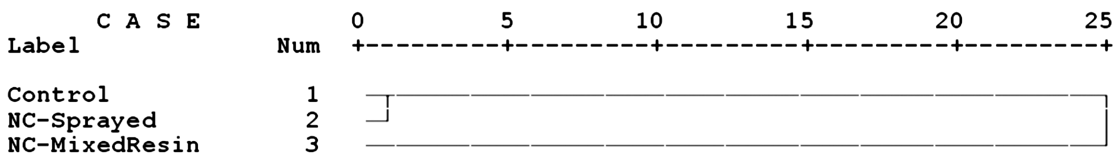

Figure 1 Cluster analysis (Ward method) of pretests based on physical and mechanical properties of medium-density fibreboard (MDF) produced for the study; NC-Sprayed = nanocopper sprayed on fibres; NC-MixedResin = nanocopper mixed with resin and then sprayed on fibres

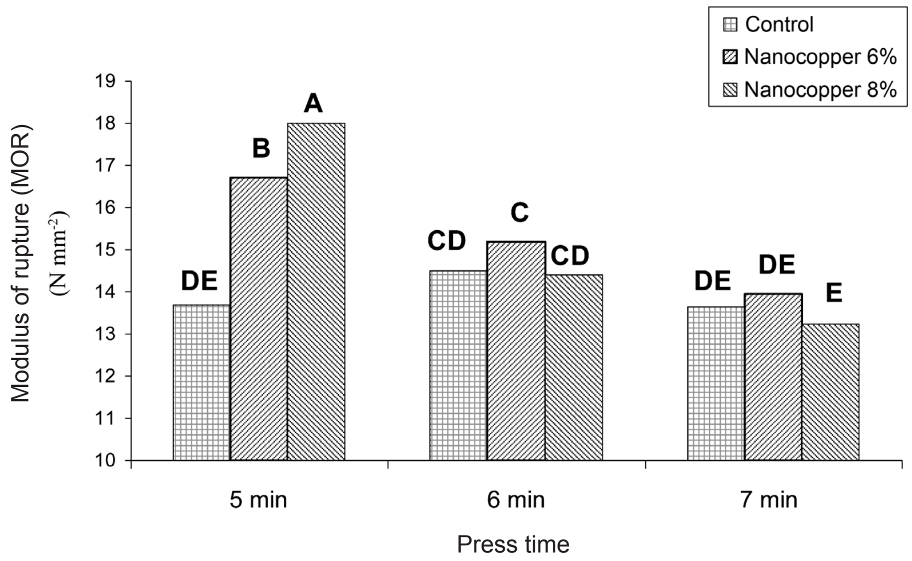

Figure 2 Modulus of rupture values at three different hot press times for each concentration of nanocopper suspension; alphabets on the columns are Duncan groupings at 99% level of confidence

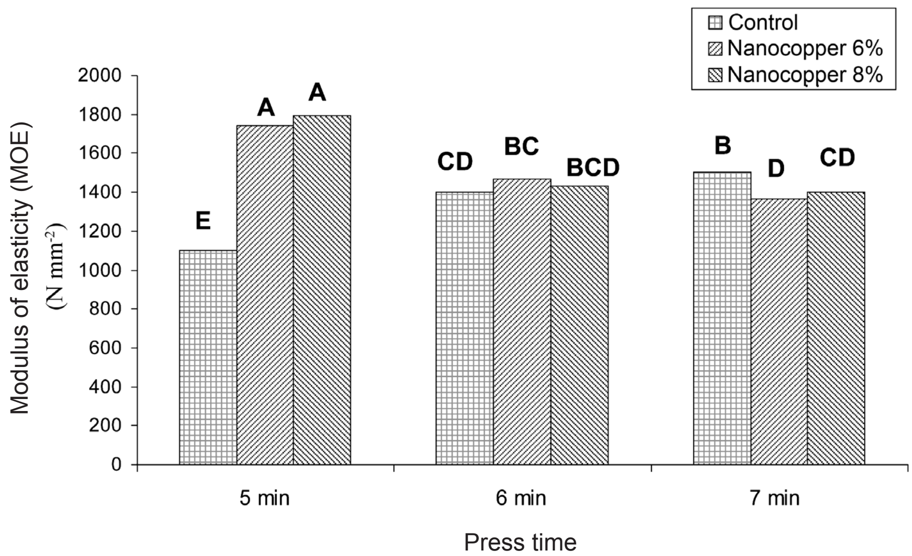

Figure 3 Modulus of elasticity values at three different hot press times for each concentration of nanocopper suspension; alphabets on the columns are Duncan groupings at 99% level of confidence

improve properties of the boards in a way to compensate for the costs of longer press time. The best properties were observed in 5-min 8% nanocopper treatment. However, rather close clustering of 6 and 8% nanocopper treatments suggests that they are more or less similar. Considering the expenses that the industries have to incur for the extra 2% of nanocopper, 6% nanocopper may be recommended for practical use in factories.

CONCLUSIONS

Heat transfer property of copper nanoparticles facilitates the polymerisation of urea formaldehyde resin in the core of the MDF

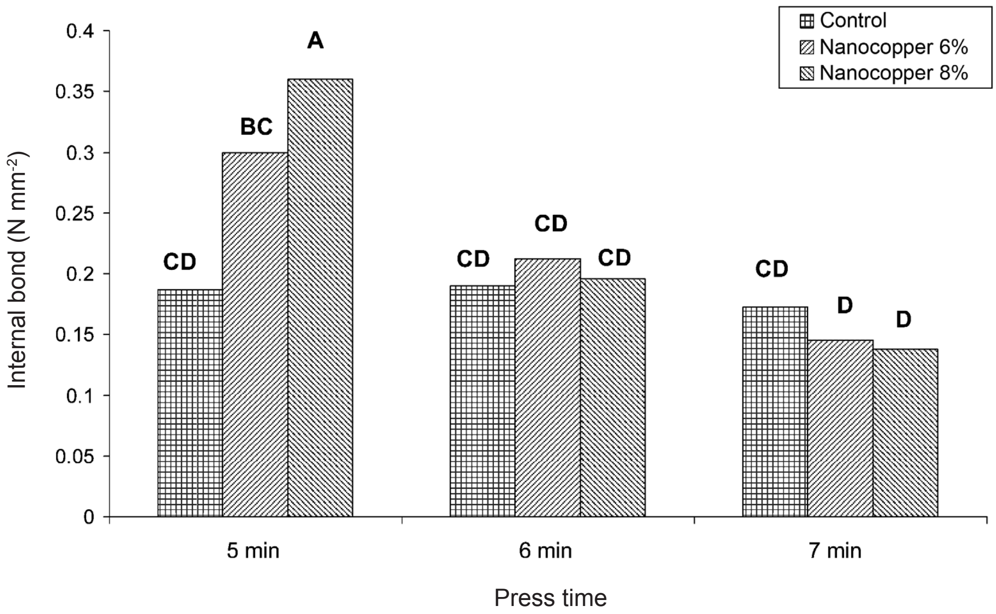

Figure 4 Internal bonding values at three different hot press times for each concentration of nanocopper suspension; alphabets on the columns are Duncan groupings at 99% level of confidence

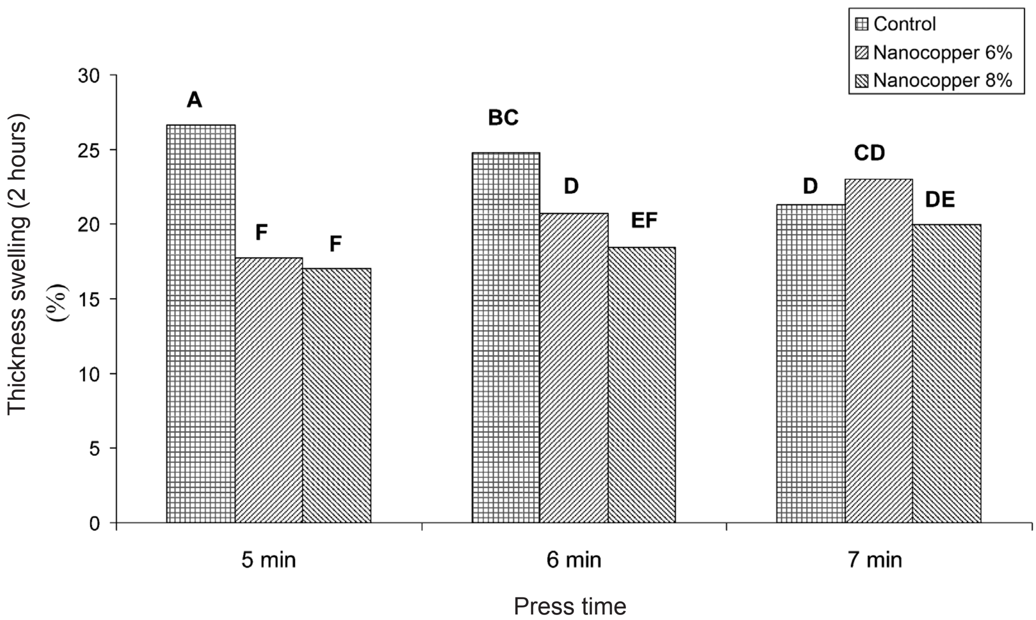

Figure 5 Thickness swelling (2 hours) values at three different hot press times for each concentration of nanocopper suspension; alphabets on the columns are Duncan groupings at 99% level of confidence

mat. With hot press time of 5 min, 6% aqueous nanocopper suspension may be recommended in the production of nanocopper-treated MDF of 16-mm thickness. This study has proven that these parameters are able to improve physical and mechanical properties of the boards.

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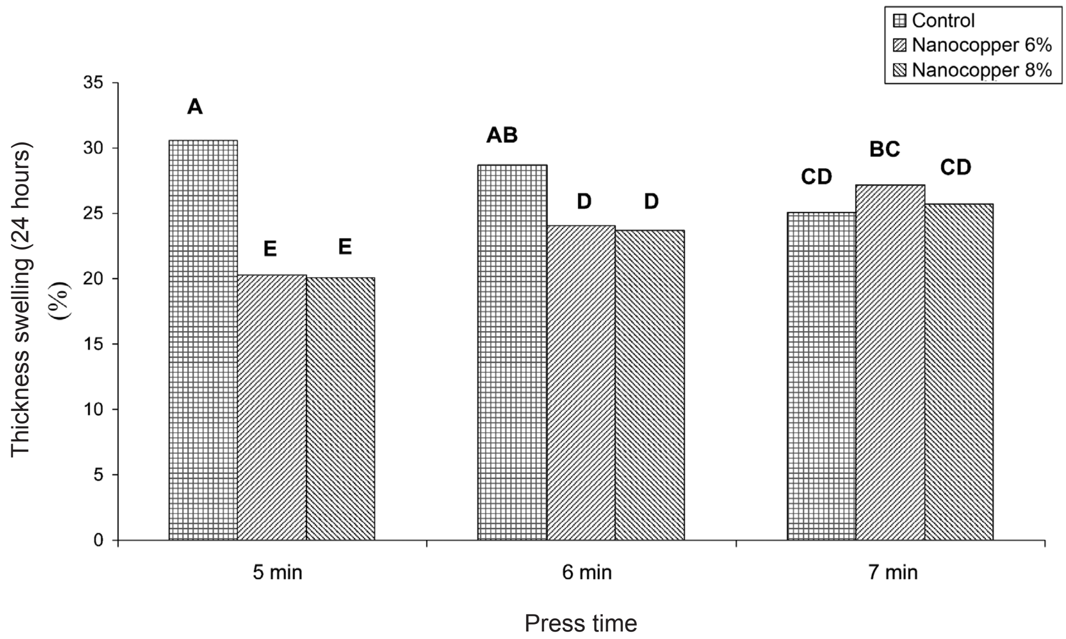

Figure 6 Thickness swelling (24 hours) values at three different hot press times for each concentration of nanocopper suspension; alphabets on the columns are Duncan groupings at 99% level of confidence

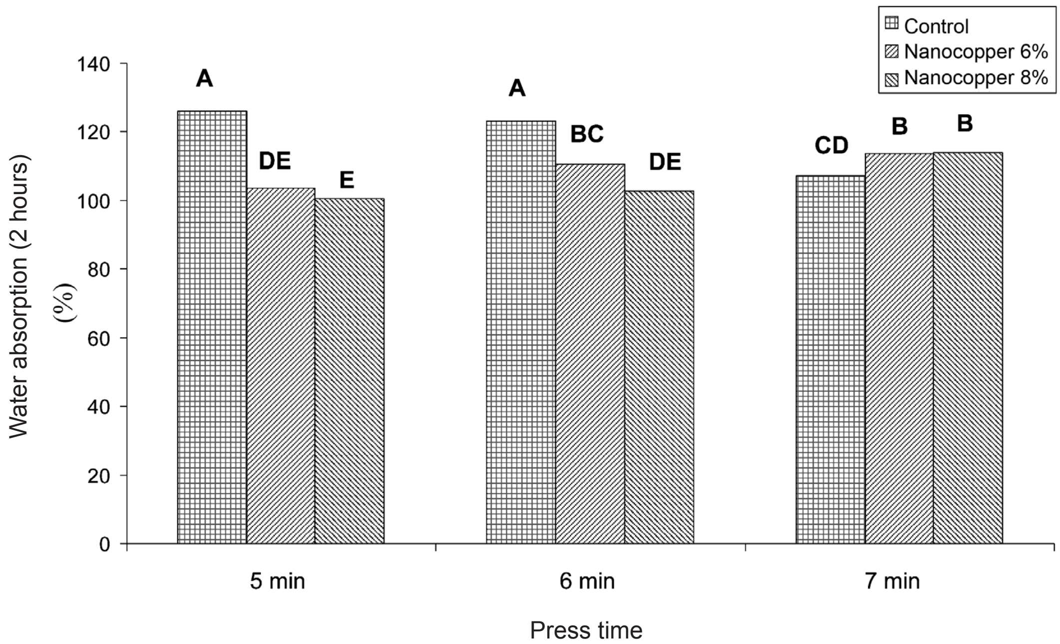

Figure 7 Water absorption (2 hours) values at three different hot press times for each concentration of nanocopper suspension; alphabets on the columns are Duncan groupings at 99% level of confidence

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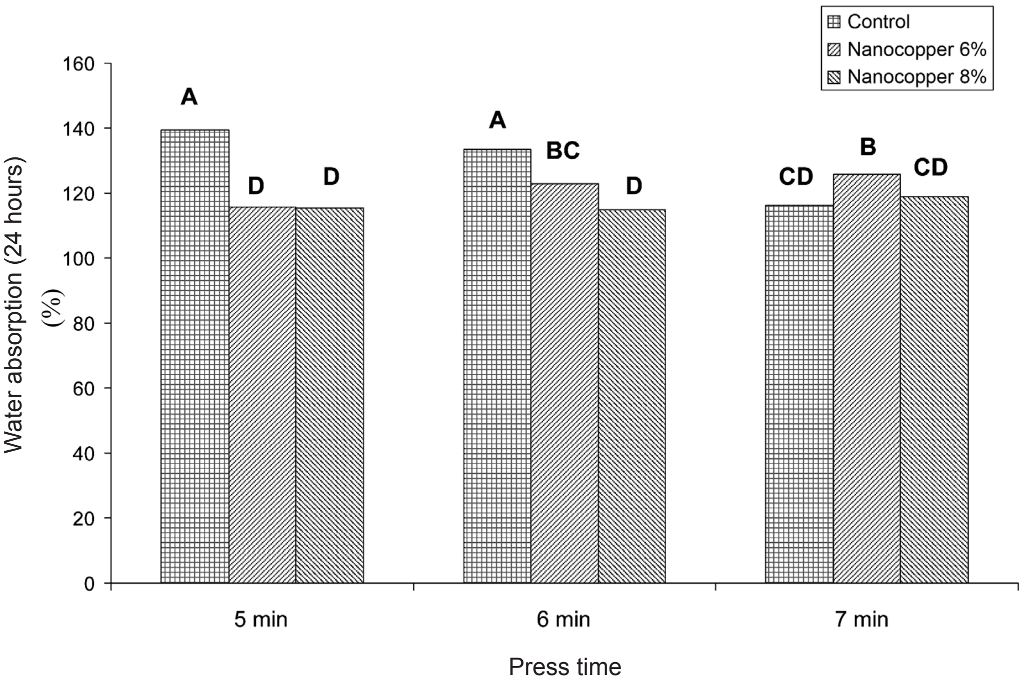

Figure 8 Water absorption (24 hours) values at three different hot press times for each concentration of nanocopper suspension; alphabets on the columns are Duncan groupings at 99% level of confidence

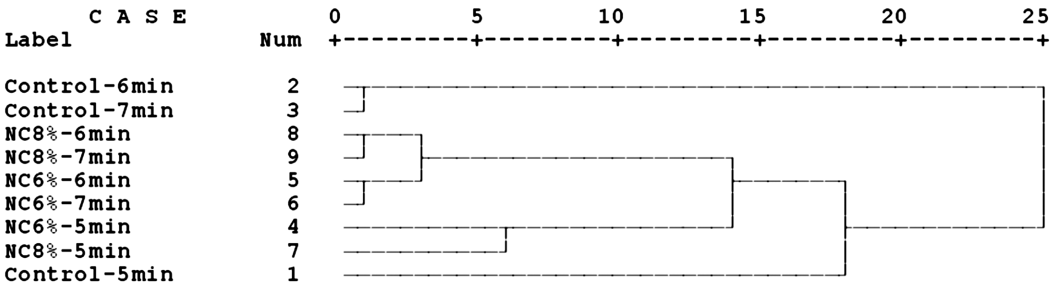

Figure 9 Cluster analysis (Ward method) of the nine treatments, namely, three different hot press times (6, 7 and 8 min) and three concentrations of nanocopper (NC) suspension (control, 6 and 8%) based on all physical and mechanical properties (modulus of rupture, modulus of elasticity, internal bonding, thickness swelling and water absorption)

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