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The *technological properties of particleboards manufactured with nano additive melamine-formaldehyde adhesive*

Nano *katkılı melamin formaldehit tutkalı ile üretilen yonga-levhaların teknolojik özellikleri*

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Abstract

In the present study, the effect of nano additives in different ratios added to melamine formaldehyde adhesives on the properties of particleboards was investigated. In this respect, two different nanoclays [organo-modified nanoclays (OMC) and unmodified nanoclays (NC)] and graphene nanoplatelet (GNP) were added to the adhesive at the rate of 1%, 2% and 4%. Along with the physical (thickness swelling and water absorption), mechanical properties (modulus of rupture, modulus of elasticity and internal bond strength), accelerated weathering and fire resistance tests (Limiting oxygen index-LOI) of the board were carried out. According to the results, while there was no significant change in the water absorption values with the use of nano additives, a decrease occurred in the thickness swelling values with the use of GNP. The mechanical properties increased with the use of nano additives. The highest values were obtained from the board groups using 1% GNP. The loss of mechanical resistance values after the accelerated weathering test was reduced with the use of 1% nanoclay and up to 2% GNP. According to LOI test results, the use of 1% and 2% nano additives increased the fire resistance of the boards., The agglomerations were determined in places with the increase in the nano additive ratio in the SEM images.

Özet

Bu çalışmada, melamin formaldehit tutkalına eklenen farklı oranlarda nano katkı maddelerinin yongalevhaların özellikleri üzerine etkisi araştırılmıştır. Bu amaçla tutkal içerisine %1, %2 ve %4 oranlarında iki farklı nanokil [organo modifiye nanokil (OMC) ve modifiye edilmemiş nanokil (NC)] ve grafen nanotoz (GNP) eklenmiştir. Levhaların fiziksel (kalınlık artımı ve su alma) ve mekanik (eğilme direnci, eğilmede elastikiyet modülü ve yüzeye dik çekme direnci) özelliklerinin yanı sıra, yapay yaşlandırma testi sonra mekanik direnç değerlerindeki değişim ve yangına dayanım (LOI) değerleri belirlenmiştir. Elde edilen sonuçlara göre nano katkı kullanımı ile su alma değerlerinde önemli bir değişim olmazken, GNP kullanımı ile kalınlık artış değerlerinde azalma meydana gelmiştir. Nano katkıların kullanımı ile mekanik özellikler ise artmıştır. En yüksek mekanik direnç değerleri %1 GNP kullanılan levha gruplarından elde edilmiştir. Hızlandırılmış yaşlandırma testi sonrası mekanik direnç değerlerindeki kayıp %1 nanokil ve %2'ye kadar GNP kullanımı ile azaltılmıştır. LOI testi sonuçlarına göre, %1 ve %2 nano katkı kullanımı levhaların yangına dayanıklılığını arttırmıştır. SEM görüntülerinde nano katkı oranının artmasıyla yer yer topaklanmalar oluştuğu belirlenmiştir.

INTRODUCTION

Wood-based composites are products that can be produced in desired shapes, sizes and thicknesses and reach a wide area of use in furniture production (coverings and panels) and in the construction industry (facades, coatings, partitions, door cores, panels, acoustic partitions) (Barbu et al. 2014). According to FAOSTAT data, the total particleboard and fiberboard (MDF and HDF) production in the world reached 200 million cubic meters in 2020, and the production amount has increased by 30% in the last ten years (FAOSTAT 2020).

Particleboard, an environmentally friendly building material, has advantages such as being produced in desired sizes, having a balanced load-carrying capacity, being light and easy to process, easy maintenance and using waste materials in production. There is also a production cost advantage over plywood and MDF (Rowell 2012).

Advances in adhesive have enabled the board industry to reach today's technology. Development of synthetic adhesive types and properties; It increased the production volume, triggered the production of new composites, and reduced the press time to 150 seconds.

This development has improved the production of fast-curing, widely available and inexpensive adhesive. Today, amino plastic adhesives for boards such as particleboard and fiberboard (MDF) are still the most important adhesives (urea and melamine and melamine-urea formaldehyde) (Muller 1992, Pizzi 2003). Due to the increasing demand for wood composites as building materials in recent years, it has become important to evaluate the possibilities of use and adhesive performance in outdoor conditions. For this purpose, applying a short-term accelerated weathering test to materials and examining the change in mechanical properties can be considered as the most practical method (Geimer et al. 1973, Kajita et al. 1991, Özgenç and Nemli 2020).

Wood and wood-based materials are composed of carbon and hydrogen and have the disadvantage of being combustible. In order for it to burn on its own, the temperature must be increased to 275°C. However, in the presence of an igniting flame source, it ignites and burns at much lower temperatures (Kobes et al. 2010, Peker and Atılgan 2015). In this regard, it has become important to improve the fire resistance properties of wood composites.

Today, scientists are heavily focused on nanotechnology. As the particle sizes get smaller, the effective surface to volume ratio increases, improving the surface and biochemical properties. Compared to other nanoparticles, nano clays are used in many studies due to their usability and low cost, as well as their high surface area of 500-1000 m^2 (Bhat et al. 2008). Among the many nanomaterials, nanoclays have become increasingly popular due to their favorable mechanical performance, high aspect ratio, and potential exfoliation properties (Majid et al. 2020). Due to its accessibility, affordability, and environmental friendliness, nanoclay has been employed in several industries, including the textile, polymer, food packaging, and medical fields (Majeed et al. 2016, Abd-Elnaiem et al. 2022). Carbon-based nanomaterials such as carbon nanotubes (CNT) and graphene nanoplatelet (GNP) have superior mechanical and electrical properties. They have been ideal fillers, especially for polymer nanocomposites (Sengupta et al. 2011). Graphene is examined the progressive material of the present times. A single graphite monolayer with one atom has 0.34 nm thickness that synthesis is complex and not yet mass produced. Even though, it's lateral size can be several orders of magnitude. Therefore, GNP has become an alternative with low cost and exciting features and the potential for large-scale production. GNPs are composed of several layers of graphite ranging in thickness from 0.7 to 100 nm (Choi et al. 2010). Nanocomposites with the addition of GNP show good strength, barrier properties, and excellent electrical and thermal properties. GNP can be produced on large scales and at low costs, making it an alternative material to carbon nanotubes (Yasmin and Daniel 2004, Wang et al. 2015).

Nano additives can enhance the properties of particleboard because of these superior properties. Therefore, this study aimed to evaluate the effect of nano additives on the physical and mechanical properties, weathering performance, fire resistance and morphological properties of particleboards and their resistance to semi open outdoor conditions.

MATERIALS AND METHODS

Materials

The particles used in the production of the boards were provided from Kastamonu Integrated Wood Industry and Trade Inc. Hybrid particles are used in the production of the boards. In the mixture, pine, poplar and beech trunks and branches, timber waste (65%) and industrial sawdust (35%) are used. Organo-modified nanoclay (OMC) was obtained from Esan Eczacıbaşı Industrial Raw Materials Industry and Trade Inc. The degree of purity is 85-90 %. Dimethyl ammonium chloride salts were used for surface modification in the production of clays. Interlayer distance: 38-40 Å and grain size less than 15 microns (Sepet 2014). Hydrophilic bentonite nanoclay (NC) was provided by Sigma–Aldrich. The bulk density value of unmodified nanoclay is 600-1100kg/m^3, and their length is less than 25 microns. Graphene Nanoplatelet (GNP) was received from Nanografi Nanotechnology Co. Ltd. The degree of purity is 99%. The nanoparticle thickness is 5 nm, the diameter is 30 µm and the specific surface area is 170 m^2/g. Melamine formaldehyde adhesive with a solids content of 54% was used in production, and Alton HM 1010 was used as a hardener.

Method

A laboratory-type Heraeus drying oven was used to dry the particles. The drying temperature is 105 ℃, and the particles are dried up to 3% moisture content. The mixing process of nano additives into adhesive was carried out in three stages. In the first stage, mechanical mixing was applied at 1000-1200 rpm for 15 minutes, and then

mixing was carried out in the homogenizer at 10000-20000 rpm for 15 minutes. This homogenizer method is widely available and has been used in many investigational studies (Kiu et al. 2017, Kranauskaitė et al. 2017, Ibrahim et al. 2019). Finally, mechanical mixing was applied again for 30 minutes. In the production of the boards, 11% adhesives were used in the surface layer and 9% in the core layer. Drais gluing machine and spray gun were used for gluing. Glued chips were laid on a 550 mm x 550 mm x10 mm board draft mold, 40% of the surface layer and 60% of the core layer. The target board density was determined as 0.650 gr/cm^3. Press pressure and press temperature for the boards were applied as 22–24 N/mm^2 and 150 ºC for 7 minutes, respectively. After production, the boards were conditioned at 20±2ºC temperature and 65±5% relative humidity conditions.

The physical and mechanical properties of the boards were determined by water absorption (ASTM D1037 2006), thickness swelling (EN 317 1999), modulus of rupture, modulus of elasticity (EN 310 1999) and internal bond strength (EN 319 1999). To determine the outdoor performance of nano additives, accelerated weathering was performed with the QUV (Q-Lab) test device. The test was carried out by modifying the ASTM G-154 (2000) (cycle 2) standard. The test cycle was carried out for 104 hours at a temperature of 60°C, 4 hours of high lamp brightness UV (0.71 W/m^2/nm) and 4 hours of condensation at 50°C. Limited Oxygen index tester (Dynisco LOI chamber) was used in accordance with the ASTM D2863-06a (2006) standard to determine the burning resistance of the samples. Sample dimensions were prepared to be 120 mm x 15 mm x 10 mm. Carls Zeiss Evo LS-10 scanning electron microscope was used for SEM analysis to determine morphological features. The IBM SPSS 23 Statistical Package Program was used for statistical analysis. ANOVA analysis and the Duncan test were used to evaluate the results. The production plan for the boards is given in Table 1.

RESULT AND DISCUSSION

Physical and Mechanical Properties

The physical properties of the boards and statistical analysis results are given in Figure 1 and Table 2. The 24-hour water absorption (WA) values of the boards were found to be between 60.89% and 67.54%. Thickness swelling (TS) values were found between 15.22% and 18.02%. The TS values limit values of particleboards are given as 15% in EN 312 (2012). The TS values of the boards were found to be barely higher than the standard. According to the DUNCAN test results, the nano additive type and the amount of nano additives did not have a positive effect on the WA values. There was a slight increase in WA values when 4% nano additives were used. TS values decreased with the use of 1% and 2% nano additives and the use of GNP. During the pressing of the board, the cell walls of the chips collapse and/or crack with the influence of heat and pressure. This situation causes the dimensional stability of wood composites in contact with moisture to deteriorate. Nano additives can increase dimensional stability by closing these cracks and water transport paths (Shi et al. 2007). Mazaheri et al. (2022) reported that there was a decrease in TS values with the addition of carbon nanotubes to urea formaldehyde adhesive in MDF production. Gul et al. (2020) determined that with 5% carbon nanotubes in MDF production, a 45% decrease in thickness increment values occurred.

Table 1. Production conditions of boards using nano additives

Board group	Organo-modified nanoclay (%)	Unmodified nanoclay (%)	Graphene nanoplatelet (%)
C	-	-	-
OMC1	1	-	-
OMC2	2	-	-
OMC4	4	-	-
NC1	-	1	-
NC2	-	2	-
NC4	-	4	-
GNP1	-	-	1
GNP2	-	-	2
GNP4	-	-	4

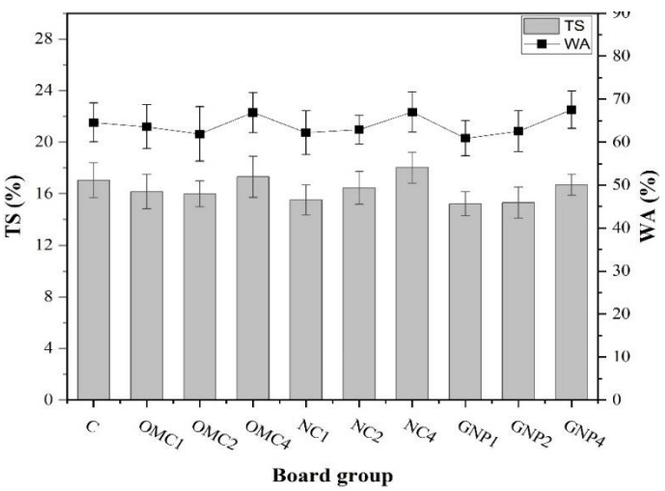


Figure 1. The effect of using nano additives on the physical properties of the boards

The mechanical properties of the boards and statistical analysis results are given in Figure 2 and Table 2. Modulus of rupture (MOR) values of the boards were found to be between 9.07 MPa and 13 MPa. Modulus of elasticity (MOE) values were found between 1231 MPa and 1661 MPa. The minimum MOR and MOE values of the general-purpose particleboards used in dry conditions are given as 12.5 and 1800 MPa in TS EN 312 (2012), respectively. The results of the DUNCAN analysis indicated that the effect of nano additive usage and nano additive ratio on MOR and MOE values was significant. The internal bond strength (IB) values of the boards were found between 0.29 and 0.42 MPa. According to the results of the DUNCAN analysis, the use of nano additives positively affected the IB values. The highest values were obtained from the board group using 1% GNP. Thanks to the high specific surface areas and 2D geometry provided by GNPs, it provides an important advantage in improving polymer properties (Saleem et al. 2016). The small size of the nano additives increases surface activities. Thus, it can fill the pores of the matrix in the composite structure, reduce the voids and improve its mechanical properties (Wu et al. 2020). In addition, an extremely strong structure is formed in composites due to the entrapment of polymer chains in the clay platelet galleries. This strong structure positively affects the mechanical properties (Muñoz and Moya 2018). In general, the improvement in mechanical properties decreased with the increase of the nano additive ratio. With the increase of the nano additive ratio, agglomerations occur in the adhesive. This may cause the adhesive line to be more fragile and the adhesion resistance to decrease (Reis et al. 2017).

Mechanical Properties After Accelerated Weathering Test

The mechanical test results of the boards after the accelerated weathering test and the amount of decrease (%) in mechanical properties are given in Figure 3. In comparison to the control groups, the modulus of rupture and modulus of elasticity decreased less when 1% of nanoclays and 1% and 2% of GNP were used. The use of nano additives at a rate of 1% improved the internal bond strength of the boards after the accelerated weathering test. It is thought that the decrease in mechanical properties after accelerated weathering is due to the change in the board's moisture content at the conditioning phase. With the weathering process, the moisture of the boards is constantly changing, while the boards are constantly under the effect of contraction and expansion (Kajita et al. 1991, Özgenç and Nemli 2020).

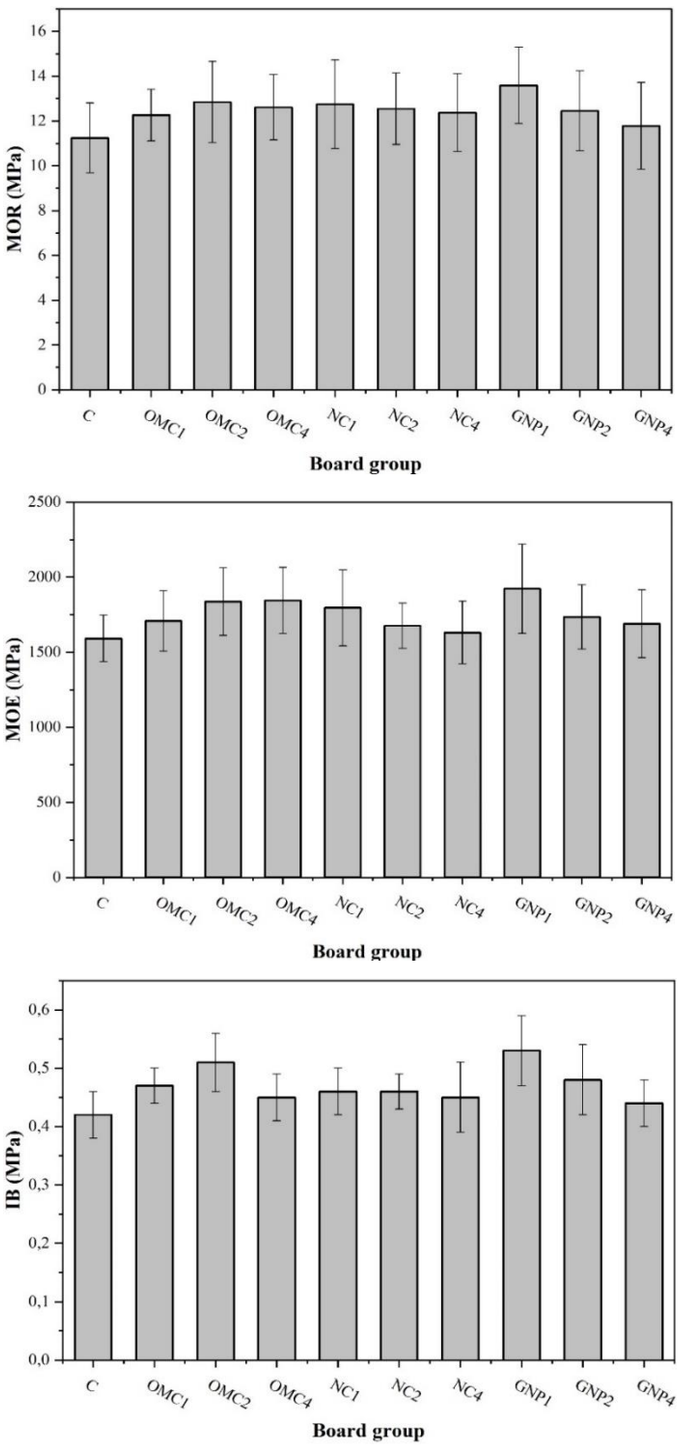


Figure 2. The effect of using nano additives on the mechanical properties of the boards

Nanoclays significantly reduce water vapor diffusion. The tortuous path theory, which pertains to the orientation of the nanoclay platelets, is used to explain barrier improvements. As a result of the intercalation reaction, the effective path length for molecular diffusion

Table 2. Statistical analysis results of the physical and mechanical properties of the boards

Properties	Tests of between-subjects effects	P value	Homogenous subsets			
	Nano filler type (A)	ns*	C	A	0%	A
WA	Nano filler content (B)	***	OM NK	A	1%	A
	A*B	ns	Na NK	A	2%	A
			GNP	A	4%	B
	Nano filler type (A)	***	C	B	0%	B
TS	Nano filler content (B)	***	OM NK	B	1%	A
	A*B	ns	Na NK	B	2%	A
			GNP	A	4%	B
	Nano filler type (A)	*	C	B	0%	C
MOR	Nano filler content (B)	*	OM NK	A	1%	A
	A*B	**	Na NK	A	2%	AB
			GNP	A	4%	B
	Nano filler type (A)	**	C	B	0%	B
MOE	Nano filler content (B)	*	OM NK	A	1%	A
	A*B	***	Na NK	A	2%	A
			GNP	A	4%	A
	Nano filler type (A)	**	C	C	0%	C
IB	Nano filler content (B)	***	OM NK	AB	1%	A
	A*B	***	Na NK	B	2%	A
			GNP	A	4%	B

Note: ns (not significant), * (significant on α=5%), ** (significant on α=1%), *** (significant on α=0.1%)

increases, the path becomes highly convoluted, and the effect of gas and moisture passage through the film decrease. As the platelet amount increases, the barrier properties become stronger. The water vapor barrier effect is weakened by agglomeration and increased photodegradation when large volumes of nanoclay are used (Vartiainen et. al. 2010, Duan et al. 2013).

The main effect of GNP in the polymer is the absorption of UV energy and the scavenging of oxidation-forming radicals. The use of GNP increases the stiffness of the polymer structure and reduces the photooxidation effect. As the amount of carbon additive increases, it does not provide sufficient distribution in the adhesive and the required surface area protective layer may not be formed. When a homogeneous mixture cannot be achieved, the inability to absorb the UV light causes it to scatter more and the UV stabilization is insufficient (Mistretta et al. 2019). GNP also prevents the transmission of UV light. This limits the formation of photodegradation products and degradation is delayed (Infurna et al. 2020).

Limiting Oxygen Index (LOI) Test

The LOI values of the board groups are given in Figure 4. The LOI values of the boards were found between 33.7 and 34.5%. While there was a slight increase in LOI values with the use of 1% and 2% nano additives, the use of 4% nano additives had a negative effect on the LOI values in general. Flame retardant effect of nano additives is directly related to the coal layer formed during combustion. This coal layer not only has a flame-retardant effect, but also creates an insulating barrier layer between the gases required for combustion and the material (Powell and Beall 2007, Hamdani et al. 2009). Deka and Maji (2011) investigated the effect of nanoclay and nano TiO_2 in OPK production on LOI values and determined that the addition of nano additives increased LOI values. In the use of high-concentration TiO_2, there was a decrease in the values. In studies on the fire performance of nanoclay, it has been determined that adding nanoclay at an appropriate rate reduces the heat release values. In addition, it has been determined that it has a reducing effect on mass energy transfer by providing coal formation. The glassy layer formed on the surface of the material during combustion prevents

contact of combustible oxygen (Bourbigot and Fontaine 2010).

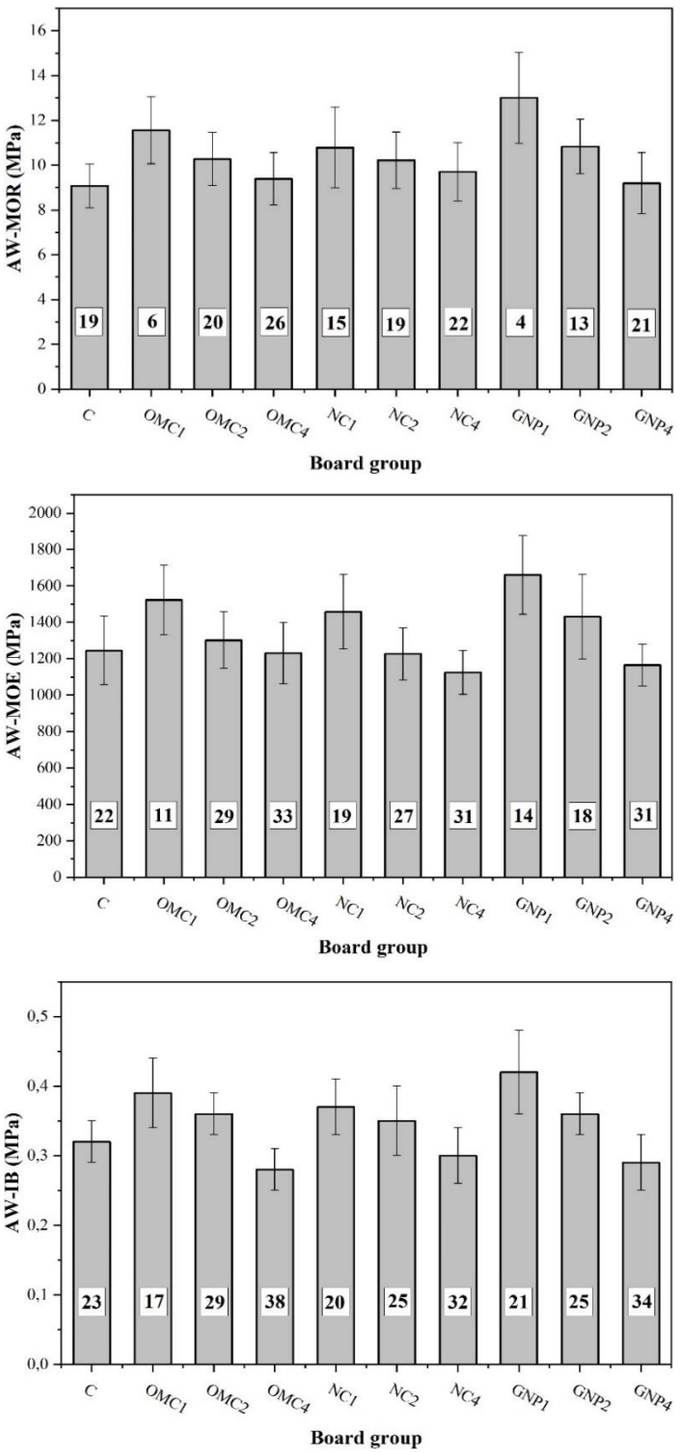


Figure 3. Mechanical properties (MPa) and reduction ratio (%) of boards after accelerated weathering test

Carbon-based nanomaterials also create a heat barrier while burning, allowing the heat to reach the inner parts of the boards later (Dittrich et al. 2013, Liu et al. 2018). In the study conducted to determine the carbon barrier effect of GNP on the flame, it was determined that the LOI values increased due to the inhibition of thermal oxidation with the addition of 1% GNP (Ran et al. 2014). The oxygen barrier effect decreases with the effect of agglomeration that occurs with high rates of nano additives (Honaker et al. 2017). According to Wang et al. (2007), using 1.5% nanoclay resulted in an improvement in the nanocomposite coatings' fire resistance qualities, whereas using 3% nanoclay had the opposite effect. This may cause a slight decrease in LOI values at high nano additive usage rates.

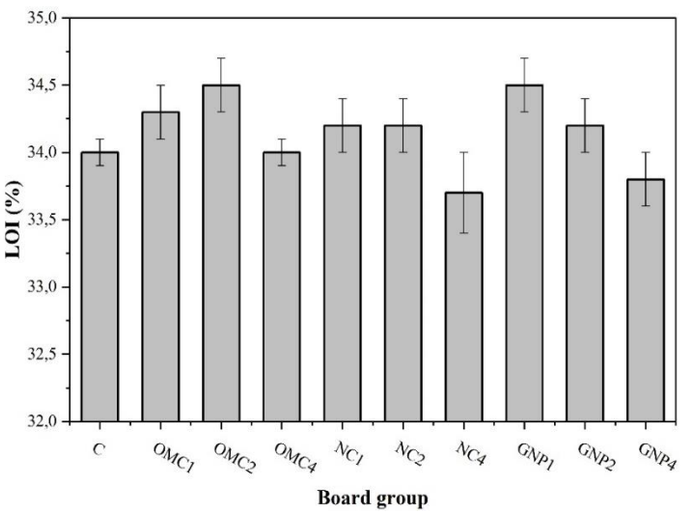


Figure 4. The effect of the use of nano additives on the combustion properties of the boards

Scanning Electron Microscopy (SEM) Analysis

SEM images of boards with 1% and 4% nano additives are given in Figure 5. The low usage rate of nano additive generally showed a more homogeneous distribution. This provided sufficient surface area and barrier effects. It has been observed that with the use of a low rate of nano additives, a less porous surface structure is formed, and with the increase of the nano additive ratio to 4%, the nanoclay and GNP grains agglomerate more clearly. The agglomerations are shown in the circle in SEM images. Due to these agglomerations, micro-voids are formed in the plate and the adhesion properties of the adhesive are adversely affected. While it is observed that the agglomeration increases with the increase in the amount of GNP use, a homogeneous distribution is observed in places and agglomerate formation is observed in places. As a result of the agglomeration of graphene particles in the mixture, the adhesion in the structure decreases and interacts with some polar groups and adversely affects the properties (Kasım 2018). The tendency to agglomerate increases with the effect of Van Der Waals

forces with the increase in the amount of GNP used (Claypole et al. 2021).

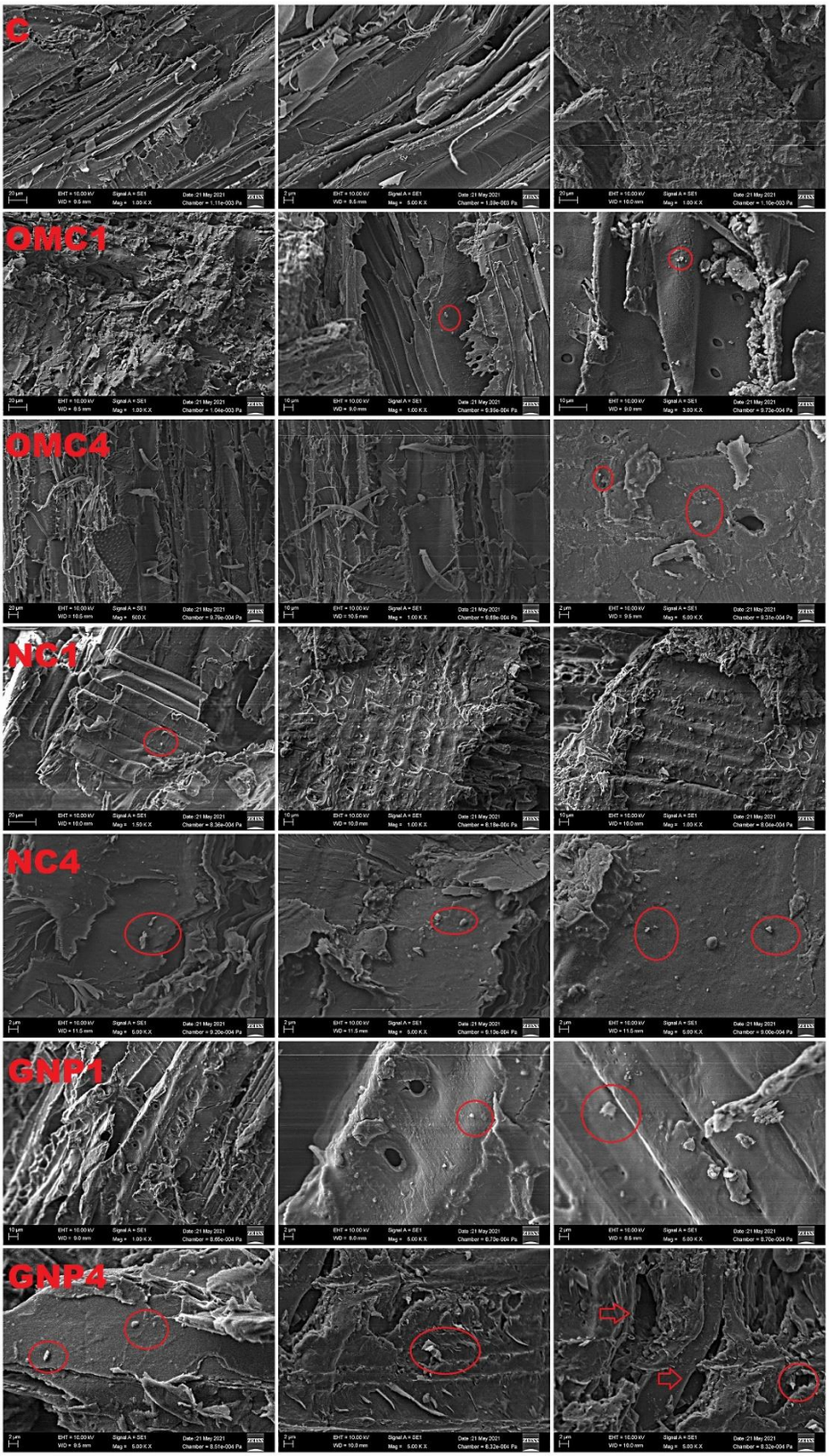


Figure 5. Scanning electron microscope images of particleboards with nano additives

CONCLUSIONS

This study investigated the effect of nano additives on physical and mechanical properties, weathering durability and fire resistance of particleboards. While there was no significant change in the amount of water absorption values with the use of nano additives in the boards, the increase in thickness swelling values decreased in the boards using GNP. With the use of nano additives, an increase in the mechanical properties of the boards has occurred. The best results were obtained from the board group using 1% GNP. It was determined that the use of nano additives influenced the mechanical properties after the outdoor test. In general, with the use of 1% nanoclay and 1-2% GNP, there was less loss of mechanical resistance after the QUV compared to the control group accelerated weathering test. In addition, Combustion resistance increased with the use of 1% and 2% nano additives. It was determined that aggregation was more prominent especially at the high nano particles usage rate when the SEM images were examined. The conducted research proved that it is possible to use nano additives in particleboard production. However, it has been determined that keeping the usage rate low in generally affects the performance characteristics more positively.

REFERENCES

Abd-Elnaiem AM, Salman OS, Hakamy A, Hussein SI (2022) Mechanical characteristics and thermal stability of hybrid epoxy and acrylic polymer coating/nanoclay of various thicknesses. Journal of Inorganic and Organometallic Polymers and Materials, 32:2094–2102.

ASTM D1037 (2006) Standard test method for evaluating properties of wood-base fiber and particle panel materials. ASTM, United States.

ASTM D2863-06a (2006) Standard test method for measuring the minimum oxygen concentration to support candle-like combustion of plastics (oxygen index). ASTM, United States.

ASTM G-154 (2000) Standard Practice for Operating Fluorescent Light Apparatus for UV Exposure of Nonmetallic Materials, ASTM, United States.

Barbu MC, Reh R, Irle M (2014) Wood-based composites. Research Developments in Wood Engineering and Technology, IGI Global, pp 1–45.

Bhat G, Hegde RR, Kamath MG, Deshpande B (2008) Nanoclay reinforced fibers and nonwovens. Journal of Engineered Fibers and Fabrics, 3(3): 22-34.

Bourbigot S, Fontaine G (2010) Flame retardancy of polylactide: an overview. Polymer Chemistry, 1(9): 1413-1422.

Choi W, Lahiri I, Seelaboyina R, Kang YS (2010) Synthesis of graphene and its applications: a review. Critical Reviews in Solid State and Materials Sciences, 35: 52–71.

Claypole A, Claypole J, Claypole T, Gethin D, Kilduff L (2021) The effect of plasma functionalization on the print performance and time stability of graphite nanoplatelet electrically conducting inks. Journal of Coatings Technology and Research, 18(1): 193-203.

Deka BK, Maji TK (2011) Effect of TiO_2 and nanoclay on the properties of wood polymer nanocomposite. Composites Part A: Applied Science Manufacturing, 42(12): 2117-2125.

Dittrich B, Wartig KA, Hofmann D, Mülhaupt R, Schartel B (2013) Carbon black, multiwall carbon nanotubes, expanded graphite and functionalized graphene flame retarded polypropylene nanocomposites. Polymers for Advanced Technologies, 24(10): 916-926.

Duan Z, Thomas NL, Huang W (2013) Water vapour permeability of poly (lactic acid) nanocomposites. Journal of membrane Science, 445: 112-118.

EN 310 (1999) Wood-based panels, determination of modulus of elasticity in bending and bending strength. EN, Brussels, Belgium.

EN 312 (2012) Particleboards-specification. EN, Brussels, Belgium.

EN 317 (1999) Particleboard and fiberboards, determination of swelling in the thickness after immersion. EN, Brussels, Belgium.

EN 319 (1999) Particleboards and fiberboards, determination of tensile strength perpendicular to the plane of the board. EN, Brussels, Belgium.

FAOSTAT (2020) Global Forest Products Facts and Figures. FAO Forestry Department, https://www.fao.org/forestry/statistics/80570/en/ (26 January 2023).

Geimer RL, Heebink BG, Hefty FV (1973) Weathering characteristics of particleboard. US Department of Agriculture, Forest Service, Forest Products Laboratory.

Gul W, Alrobei H, Shah SRA, Khan A, Hussain A, Asiri AM, Kim J (2020) Effect of embedment of MWCNTs for enhancement of physical and mechanical performance of medium density fiberboard. Nanomaterials, 11(1): 29.

Hamdani S, Longuet C, Perrin D, Lopez-Cuesta JM, Ganachaud F (2009) Flame retardancy of silicone-based materials. Polymer Degradation Stability, 94(4): 465-495.

Honaker K, Vautard F, Drzal LT (2017) Investigating the mechanical and barrier properties to oxygen and fuel of high density polyethylene–graphene nanoplatelet composites. Materials Science and Engineering, B (216): 23-30.

Ibrahim F, Mohan D, Sajab MS, Bakarudin SB, Kaco H (2019) Evaluation of the compatibility of organosolv lignin-graphene nanoplatelets with photo-curable polyurethane in stereolithography 3D printing. Polymers, 11(10): 1544.

Infurna G, Teixeira PF, Dintcheva NT, Hilliou L, La Mantia FP, Covas JA (2020) Taking advantage of the functional synergism between carbon nanotubes and graphene nanoplatelets to obtain polypropylene-based nanocomposites with enhanced oxidative resistance. European Polymer Journal, 133: 109796.

Kajita H, Mukudai J, Yano H (1991) Durability evaluation of particleboards by accelerated aging tests. Wood Science and Technology, 25:239–249.

Kasım H (2018) The development of conductive elastomer nanocomposite materials using carbon-based nano-filling materials: Progress on electrical, physical and mechanical characterization and sensing performance under static and cyclic dynamic loads. Ph.D. Thesis, Bursa Uludag University, Institute of Science, Bursa.

Kiu SSK, Yusup S, Chok VS, Taufiq A, Kamil RNM, Syahrullail S, Chin BLF (2017) Comparison on tribological properties of vegetable oil upon addition of carbon based nanoparticles. In IOP Conference Series: Materials Science and Engineering, 206(1): 012043.

Kobes M, Helsloot I, De Vries B, Post JG (2010) Building safety and human behaviour in fire: A literature review. Fire Safety Journal, 45: 1–11.

Kranauskaitė I, Macutkevič J, Borisova A, Martone A, Zarrelli M, Selskis A, Aniskevich A, Banys J (2017) Enhancing electrical conductivity of multiwalled carbon nanotube/epoxy composites by graphene nanoplatelets. Lithuanian Journal of Physics, 57(4): 232-242.

Liu ZQ, Li Z, Yang YX, Zhang YL, Wen X, Li N, Fu C, Jian RK, Li LJ, Wang DY (2018) A geometry effect of carbon nanomaterials on flame retardancy and mechanical properties of ethylene-vinyl acetate/magnesium hydroxide composites. Polymers, 10(9): 1028.

Majeed K, Hassan A, Bakar AA, Jawaid M (2016) Effect of montmorillonite (MMT) content on the mechanical, oxygen barrier, and thermal properties of rice husk/MMT hybrid filler-filled low-density polyethylene nanocomposite blown films. Journal of Thermoplastic Composite Materials, 29(7): 1003-1019.

Majid MA, Ridzuan MJM, Lim K (2020) Effect of nanoclay filler on mechanical and morphological properties of napier/epoxy composites. In Interfaces in Particle and Fibre Reinforced Composites, Woodhead Publishing, pp 137-162.

Mazaheri M, Moghimi H, Taheri RA (2022) Urea impregnated multiwalled carbon nanotubes; a formaldehyde scavenger for urea formaldehyde adhesives and medium density fiberboards bonded with them. Journal of Applied Polymer Science, 139(1): 51445.

Mistretta MC, Botta L, Vinci AD, Ceraulo M, La Mantia FP (2019) Photo-oxidation of polypropylene/graphene nanoplatelets composites. Polymer Degradation and Stability, 160: 35-43.

Muller NE (1992) An early example of a plywood support for painting. Journal of the American Institute for Conservation, 31: 257–260.

Muñoz F, Moya R (2018) Effect of nanoclay-treated UF resin on the physical and mechanical properties of plywood manufactured with wood from tropical fast growth plantations. Maderas Ciencia y tecnología, 20(1): 11-24.

Özgenç Ö, Nemli G (2020) Increasing the outdoor durability of urea formaldehyde particle board with new generation water-borne acrylic coatings. Sigma Journal of Engineering and Natural Sciences, 11(2): 159–166.

Peker H, Atılgan A (2015) Natural energy resources wood: combustion property and protection methods. Afyon Kocatepe University Journal of Science and Engineering, 15: 022201.

Pizzi A (2003) Natural phenolic adhesives. I: Tannin, In: Pizzi A, Mittal KL (ed) Handbook of Adhesive Technology, 2 edn, Marcel Dekker, New York, pp 573-589.

Powell CE, Beall GW (2007) Physical properties of polymers handbook, Physical properties of polymer/clay nanocomposites. In: James ME (ed) Springer, Germany, pp 561-575.

Ran S, Chen C, Guo Z, Fang Z (2014) Char barrier effect of graphene nanoplatelets on the flame retardancy and thermal stability of high-density polyethylene flame-retarded by brominated polystyrene. Journal of Applied Polymer Science, 131(15): 40520.

Reis MFC, Lopes CBS, Soares JD, Costa LJ, Guirardi BD, Faria BFH, Carneiro ACO (2017) Effect of the addition of nanoclay (na+ montmorillonite) on the urea formaldehyde adhesive in wood bonded joints of eucalyptus sp. Australian Journal of Basic and Applied Sciences. 11(12): 51-56.

Rowell RM (2012) Handbook of wood chemistry and wood composites. 2 edn, CRC press, Florida, USA.

Saleem H, Edathil A, Ncube T, Pokhrel J, Khoori S, Abraham A, Mittal V (2016) Mechanical and thermal properties of thermoset–graphene nanocomposites. Macromolecular Materials and Engineering, 301(3): 231-259.

Sengupta R, Bhattacharya M, Bandyopadhyay S, Bhowmick AK (2011) A review on the mechanical and electrical properties of graphite and modified graphite reinforced polymer composites. Progress in Polymer Science, 36: 638–670.

Sepet H (2014) Investigation of the production and mechanical properties of nano-particle reinforced high density polyethylene nanocomposites. Master Thesis, Selcuk University, Institute of Science and Technology, Konya.

Shi J, Li J, Zhou W, Zhang D (2007) Improvement of wood properties by urea-formaldehyde resin and nano-SiO_2. Frontiers of Forestry in China, 2(1): 104-109.

Vartiainen J, Tuominen M, Nättinen K (2010) Bio-hybrid nanocomposite coatings from sonicated chitosan and nanoclay.. Journal of Applied Polymer Science, 116(6): 3638-3647.

Wang F, Drzal LT, Qin Y, Huang Z (2015) Mechanical properties and thermal conductivity of graphene nanoplatelet/epoxy composites. Journal of Materials Science, 50(3): 1082-1093.

Wang ZY, Han EH, Ke W (2007) Fire-resistant effect of nanoclay on intumescent nanocomposite coatings. Journal of Applied Polymer Science, 103(3): 1681-1689.

Wu Q, Miao WS, Gao HJ, Hui D (2020) Mechanical properties of nanomaterials: a review. Nanotechnology Reviews, 9(1): 259-273.

Yasmin A, Daniel IM (2004) Mechanical and thermal properties of graphite platelet/epoxy composites. Polymer, 45(24): 8211-8219.