Production of Polymer Matrix Composite Particleboard from Pistachio Shells and Improvement of its Fire Resistance by Fly Ash

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ABSTRACT

The purpose of this study was to produce environment friendly construction material using pistachio shells and urea-formaldehyde and improve its non-flammable feature by using fly ash as a flame retarder. For the production of composite particleboard, urea-formaldehyde and crushed pistachio shells were mixed at different ratios ranging 0.66 to 1.22 urea-formaldehyde/pistachio shells and dried in an oven at 333 K for 24 hours. The experimental results showed that the maximum hardness and three point bending strength were 64.7 Shore A and 1.45 N/mm^2, respectively, at urea-formaldehyde/pistachio shell ratio of 1. To determine the fire resistance, composite particleboard with optimum urea-formaldehyde/ pistachio shells ratio of 1.0 was mixed with fly ash up to 20 mass % of total mass. The burning tests showed that although the maximum flame temperature of the composite particleboard without fly ash was 795 K this value decreased to 568 K with the addition of 20 mass % fly ash. This decrease resulted from the inert characteristic of fly ash at fire. It can be deduced from the burning test results that fly ash can be used in the composite particleboard as a flame retarder instead of chemicals or mineral agents. Optimum values recorded in this work may be applied to industrial applications and thus, non-flammable particle boards with fly ash can be used in interior applications.

Keywords: Particleboard, Pistachio shell, Fire resistance, Fly ash.

1. INTRODUCTION

The demand for solid wood has increased considerably, but the production of industrial wood from the natural forest continues to decline mainly due to depletion of the resources, the use of forest fields for other purposes and population growth. Therefore, there is a need for alternative resources to substitute solid wood material /1/. The use of agricultural and industrial residues as raw materials has received considerable attention in recent years because of their abundance, renewability and being environmentally friendly. The utilization of a variety of the agricultural residues in the production of biomass-based panels, such as particleboard, fiberboard and plywood, has recently increased dramatically throughout the world as an alternative to solid wood, especially for housing construction and furniture manufacturing.

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Hardboard, fiberboard, particleboard and insulation board are of very recent origin and they are conceived and developed in the research laboratories and pilot plants. They are generally manufactured from comminuted wooden in the form of shavings, fibers and agricultural wastes. Among boards, particleboards are the most popular materials used in interior and exterior applications such as floor, wall, laminated board and ceiling panels, office dividers, bulletin boards, cabinets, furniture, counter tops and desk tops /2/. The production of particleboards can be related to the decided economical advantage of low cost wood raw material, inexpensive agent and simple processing. So, agricultural residues instead of wood are extensively used for the manufacture of particleboard. Among the raw materials are almond shell /3/, pomace /4/, apricot shell /5/, kiwi prunings /6/, wheat straws /7/, bamboo /8/, cotton seed hulls /9/, flax shiv /10/, rice straw-wood /11/, vine prunings /12/, coir pith /13/, walnut shell /14/ and wood flour /15/. Polymers such as urea-formaldehyde, phenol formaldehyde, melamine formaldehyde, polyethylene and polyvinylidene are commonly used as a binder. Urea-formaldehyde is the most economical and useful adhesive among these binders.

Although the particleboards have many advantages, they have the three important disadvantages of flammability, water absorption and the possibility of being attacked by insects. These disadvantages limit their usage extensively. In order to decrease flammability of particleboards, fire retarders can be implemented during the manufacturing process and applied on the surface of particleboards. These methods can be used individually or jointly. Boric acid, ammonium phosphate, ammonium sulfate, zinc chloride, phosphoric acid, dicyandiamide, sodium borate, antimony oxide are commonly used as flame resistant chemical compounds. Also, vermiculite, perlite, gypsum and cement are used as natural flame retarders .

The aim of the present study was to produce composite particleboard from pistachio shells and urea-formaldehyde and determine the effect of urea-formaldehyde/pistachio shell ratio on hardness and bending strength. Also, fly ash up to 20 mass % was added into particleboard as a flame retardant in order to define its effect on the maximum flame temperature of particleboards produced at the optimum test conditions.

2. MATERIALS AND METHOD

The chemicals employed for the production of urea-formaldehyde were of high purity 40% formaldehyde solution and 99.9% urea. 98% of pure sulphuric acid was used as a catalyst in the reactions and only one drop sulphuric acid per 60 g urea was added into the reaction medium. The experimental set-up for the urea-formaldehyde reaction consisted of a spherical flask reactor, a reflux condenser, a thermometer and a heating mantle with a magnetic stirrer. A 1000 ml three necked volumetric pyrex flask was used as a reactor. Pistachio shells were ground, sieved and dried in an oven at 378 K for about 1 h. Different amounts of urea-formaldehyde resin and 60 g pistachio shell were used throughout the study as a binder and filler, respectively.

Optimum conditions for urea-formaldehyde reaction were obtained from our earlier study /3/. Reaction temperature was controlled within ±2 K by means of thermostat. After the polymerization reactions had been completed at the specified temperature and time, pistachio shells were added into the urea-formaldehyde until it was saturated and the mixture was then cast into a mould and dried for one day at atmospheric conditions. The cast material was removed from the mould, turned of opposite surface and dried again for one day. Finally, it was dried at 343±2 K in an oven until constant weight was reached. In order to see how the manufacturing conditions affected the particleboard features, pistachio shell/urea-formaldehyde ratio and fly ash amount were chosen as parameters. Fly ash was supplied from Yatağan-Muğla coal powerplant in Turkey. The chemical composition of fly ash is given in Table 1. The burning characteristics of the composite particleboard with various amount of fly ash were determined according to the ASTM-E 160-50 standard. Briefly, burning tests were carried out firing the test specimens with a torch for 180 seconds and at the end of this period, the torch was turned off and the maximum temperature was recorded.

Table 1

Chemical composition of fly ash powder (mass %)

SiO_2	TiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	NaO	K_2O	SO_3
47.08	1.03	21.96	6.48	16.03	2.12	1.28	0.93	2.13

Mechanical properties were determined by means of hardness and bending tests. Shore A hardness test was performed using a Durotech M202 hardness tester. Three point bending test was carried out according to EN 310 standard by using Shimadzu AG-I machine. For three point bending test, the span length was 40 mm and the cross head speed was 2 mm/min. The dimension of the rectangular bending test specimen was 12 mm high, 30 mm wide and 60 mm long. A minimum of three specimens for bending tests and ten different points on each specimen for hardness tests were done in order to establish average values. Scanning electron microscopy (SEM) (JEOL 6360) was used to characterize the microstructure of composite particleboards.

3. RESULTS AND DISCUSSION

High demand for solid wood materials and forest fires increased the importance of composite particleboards. Particleboards are among the most popular board materials used in interior and exterior applications in floor, wall, ceiling panels, office dividers, bulletin boards, cabinets, furniture, counter and desk tops. The extensive use of particleboards can be related to the economical advantage of low cost wood raw material, inexpensive agents and simple processing. There is widespread use of agricultural residues for the manufacture of particleboards. Among the agricultural residues, pistachio shells are the most important ones in terms of quantity in Turkey. On the other hand, it has not drawn much attention as an agricultural residue that can be used in forest industry as raw materials for the production of particleboard. Turkey is one of the biggest pistachio producers in the world and every year tons of pistachio shells are either left in the field or burned after harvest. Therefore its possible usage is very important and gives economical as well as environmental dividends.

In our earlier study, the effect of processing parameters, namely urea/formaldehyde ratio, reaction temperature, reaction time and shell particle size on the mechanical properties were investigated and the optimum values were determined for the production of a particleboard. In these tests, the urea/formaldehyde ratio of 1, reaction time of 20 min., mean particle size of 0.4 mm and the reaction temperature of 343±2 K were recorded as the optimum values. The concentrated NaOH solution was used as a catalyst in the reactions. At the above optimum test conditions, the transition from transparent to cloudy stage, which is the indication of the completion of reaction was easily seen /3/. In the present study, one drop sulphuric acid instead of NaOH for 60 g urea was used in the urea-formaldehyde reaction medium for curing polymer without using hardener.

The effect of urea-formaldehyde/pistachio shell ratio on hardness of the composite particleboard was determined using the above optimum test conditions. The relationship between hardness and urea-formaldehyde/pistachio shell ratio is shown in Figure 1. The hardness values increased linearly with increasing urea-formaldehyde/pistachio shell ratio up to 1 and further increase in the urea-formaldehyde/pistachio shell ratio caused slight hardness decrease.

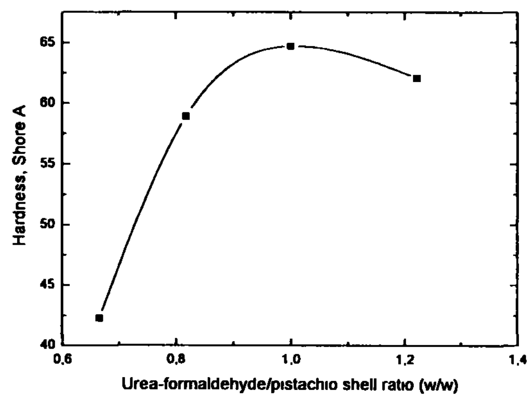

Fig. 1: The effect of urea-formaldehyde/pistachio shell ratio on hardness of composite particleboard.

Figure 2 shows the effect of urea-formaldehyde/ pistachio shell ratio on three point bending strength of particleboard. As can be seen from this figure, the bending strength increased with increasing urea-formaldehyde/pistachio shell ratio up to 1 and further increase in the urea-formaldehyde/ pistachio shell ratio led to decreased bending strength. The increase in the hardness and bending strength values with an increase in the urea-formaldehyde/pistachio shell ratio was due to the existence of enough urea-formaldehyde as a binder in the particleboard forming good adhesion between urea-formaldehyde and pistachio shells. However, slight decrease in the hardness and bending strength after the urea-formaldehyde/pistachio shell ratio of 1 resulted from the insufficient urea-formaldehyde and thus the domination of poor polymer matrix in the particleboard.

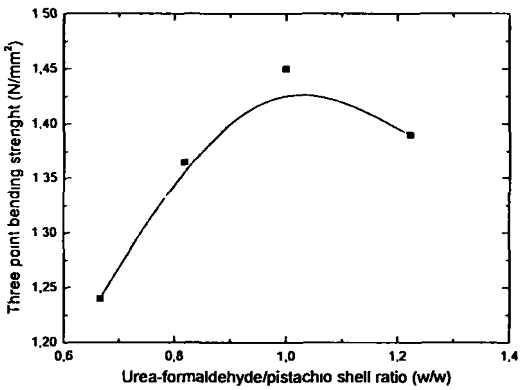

Fig. 2: Effect of urea-formaldehyde/pistachio shell ratio on the three points bending strength of composite particleboard.

To investigate the effect of fly ash addition on the flame temperature of particleboards, the experiments were carried out at urea-formaldehyde/pistachio shell of 1 using fly ash up to 20 mass % as a part of filler materials. As can be seen in **Fig. 3**, the maximum flame temperature of 795 K exponentially decreased with increasing fly ash amount in the particleboard reaching the lowest value of 568 K at fly ash amount of 20 mass %. This decrease resulted from inert characteristic of fly ash at fire. Because the fly ash consisting of mostly SiO_2, Al_2O_3 and CaO compounds has a high melting point. The addition of fly ash as a fire retardant in the particleboard also resulted in a separation of the flammable materials and a decrease of the thermal conductivity, which gives a particleboards fire-resistant property. It can be deduced from the burning test results that fly ash can be used in the particleboard as a flame retarder instead of chemicals or mineral agents.

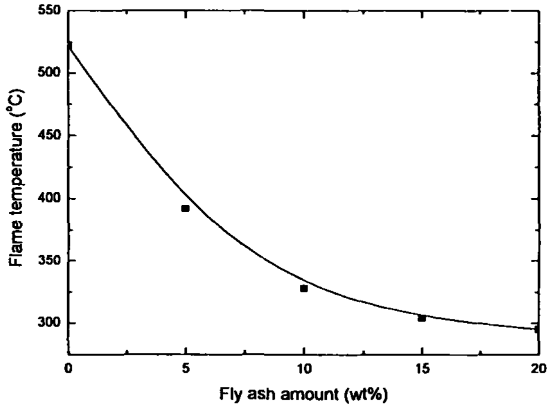

Fig. 3: Effect of fly ash on the maximum flame temperature of composite particleboard (urea-formaldehyde/pistachio shell ratio, w/w:1).

Figure 4 shows the SEM microstructures of the composite particleboard with and without fly ash. Uniformity of composite structures can be clearly seen in these figures. Also, fly ash dispersed homogeneously in the composite particleboard (Fig.4b).

4. CONCLUSION

It is concluded that the composite particleboard can be manufactured from pistachio shell, which has no economical value other than being used as very low grade fuel. Waste raw material and low operating cost make this study a promising one for technological application. Fly ash, which creates air pollution when discharged from coal power plant, can be used as a flame retarder instead of chemicals or mineral agents in the composite particleboard. Thus, its usage prevents to create environmental pollution. Optimum conditions recorded in this work may be applied to industrial process economically and are environment friendly. Obtained polymer composite particleboard can be recommended for use in interior and exterior applications securely and economically.

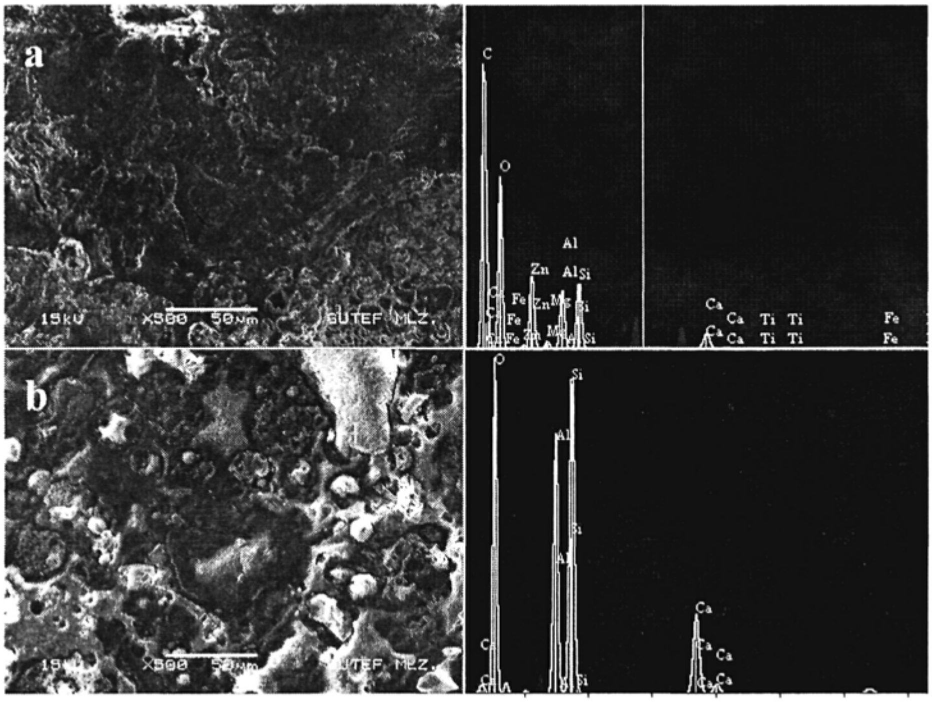

Fig. 4: SEM microstructures of the composite particleboard with (a) and without (b) fly ash.

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REFERENCES

1. Y. Çöpür, C. Güler, M. Akgül and C. Taşçıoğlu, *Building and Environment,* **42,** 2568-2572 (2007).
2. D. Wang and X.S. Sun, *Industrial and Crop Products,* **15,** 47-50 (2002).
3. M. Gürü, S. Tekeli and İ. Bilici, *Materials and Design,* **27,** 1148-1151 (2006).
4. M. Gürü, *Uçucu kül ve pirinadan yapı malzemeleri uretimi,* No: TR 2000 01751 Turkish Patent Institute (2000).
5. M. Gürü and S. Tekeli, *Twelfth Annual International Conference on Composites/Nano Engineering*, University of New Orleans, 1-6 August, (2005), Tenerife, Spain.
6. G. Nemli, H. Kirci, B. Serdar and N. Ay, *Industrial and Crop Product,* **17,** 39-46 (2003).
7. G. Han, C. Zhang, D. Zhang, K. Umemura and S. Kawai, *Journal of Wood Science,* **44,** 282-286 (1998).
8. R.M. Rowel and M. Norimoto, *Mokuzai Gakkaishi,* **34,** 627-629 (1988).
9. R.M. Gurjar, *Bioresource Technology,* **43,** 177-178 (1993).
10. A.N. Papadopoulos and J.E.B. Hague, *Industrial and Crop Products,* **17,** 143-147 (2003).
11. H.S. Yang, J.K. Dae and J.K. Hun, *Bioresearch Technology,* **31,** 736-741 (2003).
12. G.A. Ntalos and A.H. Grigoriou, *Industrial and Crop Products,* **16,** 59-68 (2002).
13. R. Viswanathan and L. Gothandapani, *Journal of Agricultural Engineering Research,* **74,** 331-337 (1999).
14. M. Gürü, M. Atar and R. Yıldırım, *Material and Design,* **29,** 284-287 (2008).
15. D.P. Kamdem, H. Jiang, W. Cui, J. Freed and M. Matuana, *Composites* **A, 35,** 347-355 (2004).