MECHANICAL PROPERTIES OF CARBONIZED MEDIUM DENSITY FIBERBOARD/POLYMER COMPOSITES

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Abstract

Carbonized medium density fiberboard (CMDF)/polymer composites were produced by impregnating the porous preforms with epoxy resin and phenolic resin. Samples infused with the epoxy resin had higher apparent density than those infused with the phenolic resin, because the former displayed a greater weight gain and less porosity than the latter. The mechanical properties of these composites were characterized by conducting four-point bending tests, dog-bone tensile tests, and single-edge-notch bending fracture toughness tests according to ASTM standards. The results showed that the epoxy resin was more favorable in improving the mechanical properties of the CMDF. It was demonstrated that the specific strength was increased considerably after resin infusion; while the specific modulus was not changed much. The results indicated that the increased specific strength was due to the improved resistance to fracture of the material.

Introduction

The practice of converting wood into carbon has been existed for many centuries, and the products have been used for fuel, absorbent, and industry raw materials. Recent studies [1, 2] on making crack-free monolithic porous carbon from wood and using it as precursors for structure ceramics and composites found a new use for wood and attracted more and more interest from different research groups. The carbon produced through controlled thermal decomposition of wood in an inert atmosphere has been shown to be able to retain the ultra-structure integrity of the parent wood [3]. It has been used as a template in the synthesis of high performance biomorphous carbide ceramics [4-6]. The carbonized wood also has been demonstrated to have excellent machinability and to be a promising precursor for making carbon/carbon and carbon/polymer composites [7]. However, their physical and mechanical properties have not been well studied.

Carbonization of natural solid wood has many limitations, such as long carbonization process for large samples, retaining of structural defects (knots), less reproducibility, and dimension limitation of products due to the size of trees. Therefore, to expand the capability of carbonized wood processing, wood based composites, such as medium density fiberboard (MDF), have been used to make porous carbon. When MDF is used as the raw material, the carbonization of large samples can be completed within one day [8], and some of the properties of the final products can be engineered through control of the density and particle sizes of MDF panels [9].

The main purpose of this study is to investigate some basic physical and mechanical properties of CMDF/polymer composites to provide reference data for future application of this new type of composites.

Materials and Methods

Carbonization of MDF

Hardwood MDF with a nominal thickness of ¾ inch, bought from Home Depot, was cut into 12 inches long and 8 inches wide pieces. The boards were carbonized in argon with a flow rate of 0.5L/min running through the entire process in a retort furnace (CM 1200 RapidTem, CM Furnace Inc., Bloomfield, NJ 07003). The thermal schedule was modified from the prior work by Nagle and co-workers [1, 2, 8] and it was briefly described as: 50 °C/h to 110 °C and dwell for 3 hours; 15 °C/h to 200 °C; 30 °C/h to 400 °C; 15 °C/h to 600 °C; 50 °C/h to 1000 °C and dwell for 1 hour; 300 °C/h to 25 °C. After carbonization there was about 40% linear shrinkage in three dimensions without deformation, and the carbonized board had a nominal thickness of 0.45 in.

Resin Infusion

The CMDF boards were machined into test coupons prior to resin infusion. For flexural properties test, bar shape coupons were used and they were 7.0 inches long, 0.9 inches wide and 0.45 inches thick. For tensile properties test, dog-bone shaped specimens were used and the overall length, overall width, length of the narrow section, and width of the narrow section were 6.5 inches, 0.875 inch, 2.25 inches, and 0.5 inch, respectively. The dimension of specimens for fracture toughness test was 4.0 inches long, 0.9 inch wide and 0.45 inch thick.

Infusion of epoxy resin: The epoxy resin system, Pro-Set 125 (resin) and 229 (hardener) by Gougeon Brothers Inc., was used in this study due to its outstanding working properties. The resin and the hardener were mixed with a weight ratio of 100:30 at room temperature according to the manual. Before infusion, the specimens were submerged in the resin mixture in a plastic container placed in a vacuum chamber. The chamber was slowly vacuumed down to 25 inches Hg pressure and this vacuum was kept for 10 minutes before the chamber was back-filled with air. Then this vacuuming process was repeated once. The specimens were taken out and their surfaces were cleaned by wiping off the excessive resin. The cleaned specimens were set at room temperature for 15 hours followed by post-curing at 83 °C for 8 hours.

Infusion of phenolic resin: The phenolic resin, Durite SC 1008 by Borden Chemicals, was selected since it was specially designed for laminates infiltration. The resin could be cured by heating to 100 °C for 30 minutes, but slight heating at a lower temperature could decrease the viscosity and facilitate the infusion before the resin is cured. Our previous studies showed that when the resin was heated to 60 °C – 70 °C, it could provide sufficient low viscosity and enough time for the resin infusion process in this study. Therefore, same vacuum procedure used in epoxy resin infusion as described earlier was applied for phenolic resin infusion, except that the resin and the specimens were heated to 65 °C prior to the application of vacuum each time.

The cleaned phenolic resin infused specimens were set at 50 °C for 24 hours and then cured using the following profile: 150 °C/h to 80 °C; 80 °C/h to 94 °C and dwell for 20 minutes; 150 °C/h to 150 °C and dwell for 60 minutes; 300 °C/h to room temperature.

Mechanical tests and calculations

A screw-driven ATS universal test machine (Series 910, Applied Test Systems Inc. Butler, PA) was used for all the mechanical tests. Dog-bone tensile test, four-point-bending test, and single edge notch fracture test were conducted to characterize the basic mechanical properties of the CMDF/polymer composites. The tensile tests, bending tests, and plane-strain fracture toughness tests were conducted and their results were calculated according to ASTM D 638, ASTM C 651, and ASTM D 5045 respectively. A constant crosshead speed of 0.05 in/min was used in all tests. All of the displacements were measured using a MTS extensometer (Model: 117-20, MTS, Eden Prairie, MN) and the data were collected by a PC system using a HP data acquisition unit (Model: 34970A, Hewlett-Packard Company, Loveland, Colorado).

Mercury porosimetry measurement

The change of total porosity and pore size distribution before and after infusion of polymer were investigated using a mercury porosimetry (AutoPore IV 9500, Micromeritics Instrument Corporation, Norcross, GA). A contact angle of 130 degrees and a surface tension value of 473 mN/m for mercury were used in the calculation of pore sizes [10].

Results and Discussion

Apparent density

The apparent density of CMDF samples infused with epoxy is greater than that of those infused with phenolic resin (Figure 1). The former had an average weight gain of 96.7%, while the weight gain of the latter was 66.7%. Because the epoxy resin used in this study was designed to cure at room temperature, during the infusion process the epoxy resin started polymerization shortly after it went into the porous carbon preforms. The heat released from the polymerization reaction further accelerated the curing process. Therefore, the resin was retained in the porous preform. However, for phenolic resin infused CMDF, the lower weight gain associated with phenolic resin was caused by bleeding of the resin during the curing process at elevated temperatures. During the infusion process, as the temperature dropped from about 65 °C to room temperature, the viscosity of the resin increased. Since the resin had not been turned into B stage after set at 50 °C for 24 hours, when the temperature increased during the curing cycle, the viscosity dropped again, resulting in bleeding of the resin. The vaporization of the solvent could also have prompted resin bleeding by forming air bubbles.

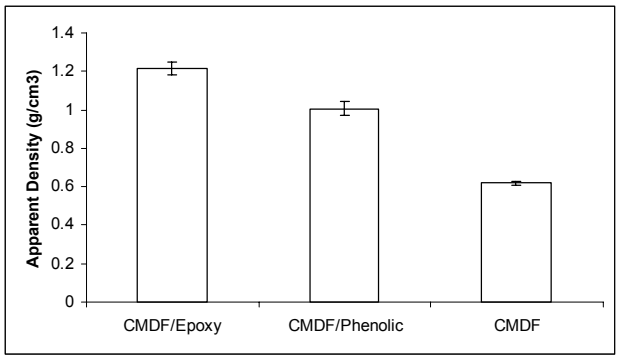

Figure 1. Change of apparent density after resin infusion.

Porosity and pore distribution

The original CMDF had a porosity of 58.94%, but after resin infusion, the porosity decreased to 4.77% for the epoxy resin infused and to 29.07% for the phenolic resin infused. Most of the pores in the original CMDF had a diameter smaller than 10 microns (Figure 2). After it was infused with epoxy resins, most of the pores were filled with resin and only small amount of pores between 2.5 microns and 9 microns were left (Figure 2 insertion). For the samples infused with phenolic resin, the pores smaller than 1.5 microns were filled, but there were a great amount of pores between 1.5 microns and 9 microns that were not filled (Figure 2 insertion). The results indicated that after the resin went into the porous carbon, it filled smaller pores before it did larger ones.

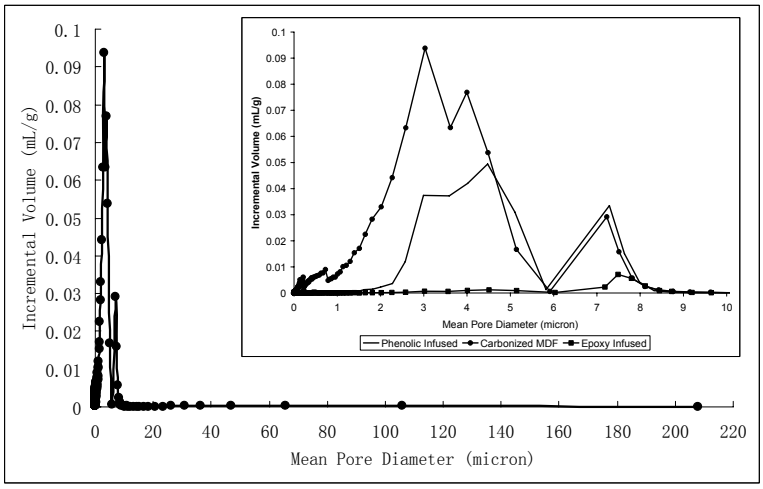

Figure 2. Pore size and distribution before and after resin infusion.

Mechanical property tests

On its tensile stress-strain profiles the original CMDF displayed an abrupt fracture behavior typical of brittle materials. Since the polymers used in this study were thermal setting resins and they became brittle after being cured, after resin infusion the composites still were brittle materials, but had greater elongations at failure (Figure 3). The tensile properties of the original CMDF were considerably increased after resin infusion (Figure 4 and 5), and the CMDF/epoxy composite had the highest tensile strength and tensile modulus. Compared to the resins used in this study, the original CMDF had inferior mechanical properties (Table 1). Therefore, after resin infusion, improvement of the mechanical properties of CMDF was to be expected. The flexural properties of CMDF were also significantly increased after infusion of the resins (Figure 6 and 7). The bending MOR increased by 219.15% and by 107.36% for samples infused with epoxy and phenolic, respectively. Adding of resins to the original CMDF significantly improved its resistance to fracture as well. The plane-strain fracture toughness increased by 442.85% for epoxy infused samples and by 257.65% for phenolic infused samples (Figure 8), indicating that the original CMDF became less brittle after resin infusion.

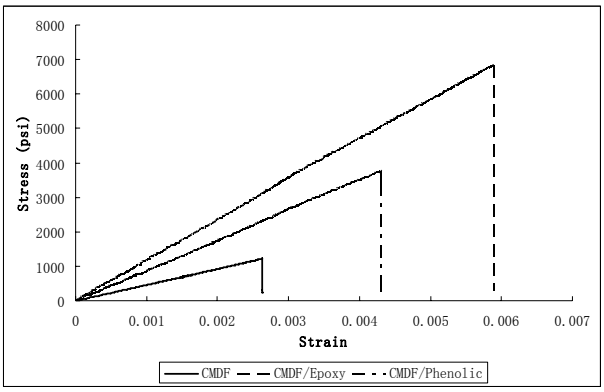

Figure 3. Typical stress-strain profiles of CMDF, CMDF/Epoxy composite, and CMDF/Phenolic composite.

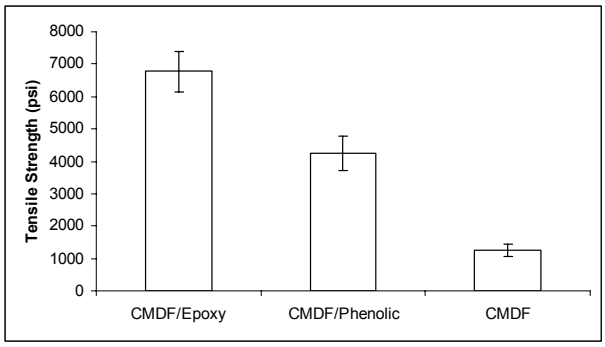

Figure 4. Change of tensile strength after resin infusion.

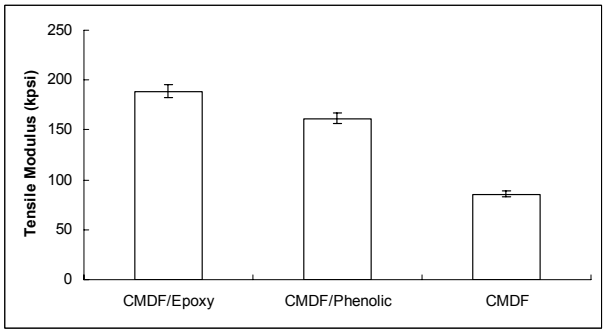

Figure 5. Change of tensile modulus after resin infusion.

Table 1. Comparison of tensile properties.

Materials	CMDF	Epoxy	Phenolic
Specific Gravity	0.619	1.143	1.276
Tensile strength (psi)	1268	9974	8900
Tensile modulus (psi)	0.86E5	4.22E5	5.70E5
Elongation at failure (%)	0.26	4.00	1.70

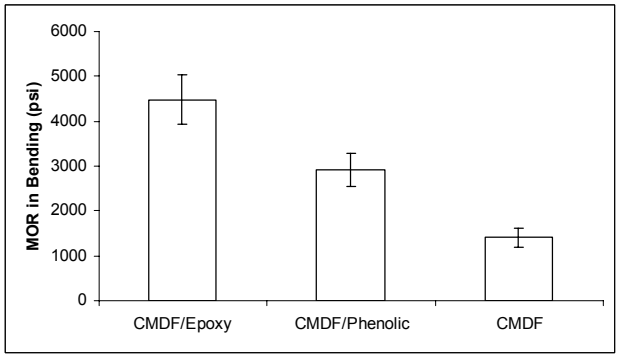

Figure 6. Change of bending MOR after resin infusion.

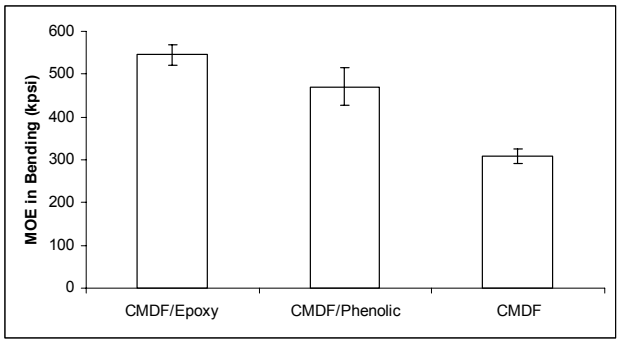

Figure 7. Change of bending MOE after resin infusion.

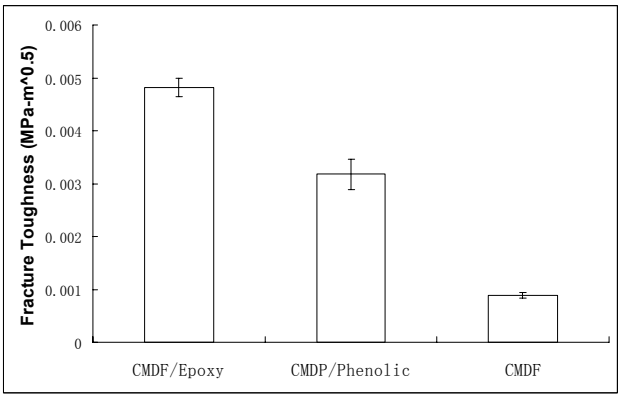

Figure 8. Change of plane-strain fracture toughness after resin infusion.

As density usually is a critical factor influencing the mechanical properties of porous material, the specific mechanical properties of these three samples were compared. It was found that there was no significant change of specific bending MOE of the original CMDF after infusion with both the epoxy resin and the phenolic resin (Figure 10), but the specific bending MOR was significantly increased for the epoxy resin infused samples (Figure 11). For the tensile properties, the specific tensile strength increased by 171.78% for the epoxy resin infused samples and by 107.70% for the phenolic resin infused samples (Figure 12). However, the specific tensile modulus was increased by only 12.29% and 15.97% respectively (Figure 13). These results indicated that the infused resins changed very little the modulus of one unit mass of the material, but considerably increased its maximum stress at bending and tensile failure.

For the resistance to fracture, the specific plane-strain fracture toughness was increased significantly, by176.43% for epoxy infused samples and by 119.94% for phenolic infused samples (Figure 14). Therefore, it has been demonstrated that the increases of bending MOR, tensile strength, and fracture toughness were independent on apparent density, but apparent density had great effect on bending MOE. The results indicated that the increase of the bending and tensile strength of CMDF/polymer composites was due to the improvement of their resistance to fracture.

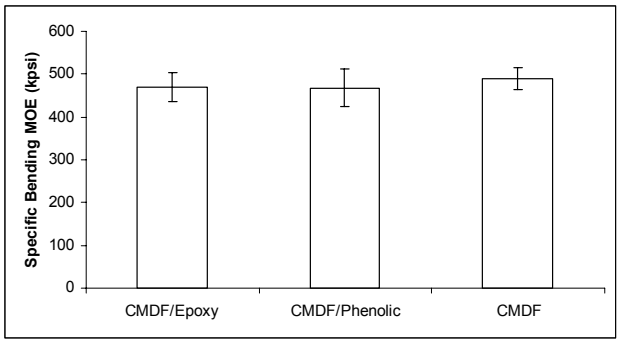

Figure 9. Change of specific bending MOE after resin infusion.

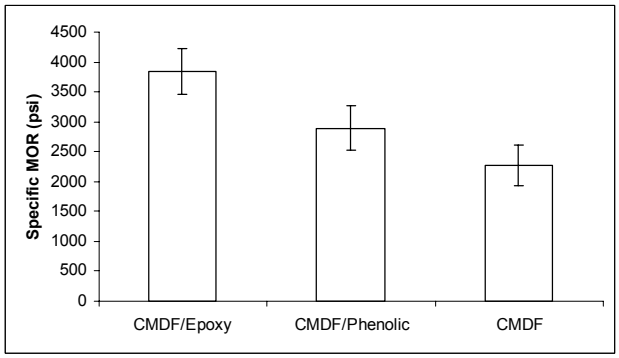

Figure 10. Change of specific MOR after resin infusion.

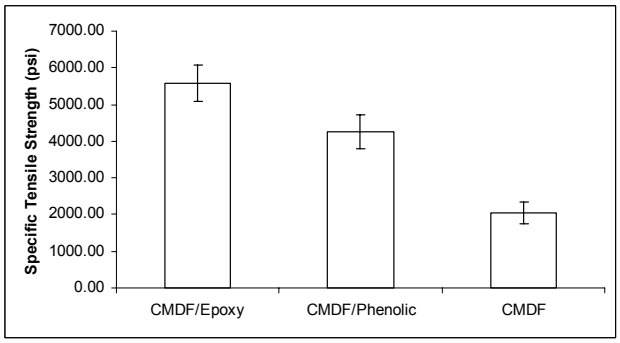

Figure 11. Change of specific tensile strength after resin infusion.

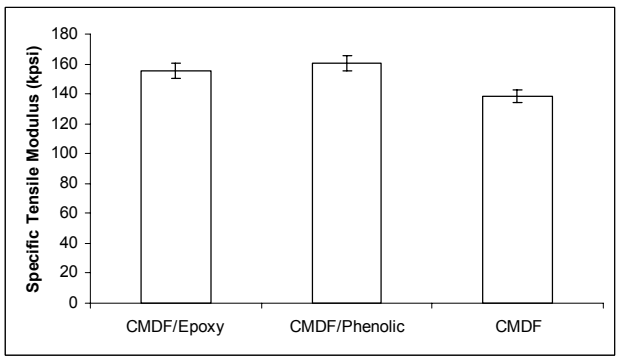

Figure 12. Change of specific tensile modulus after resin infusion.

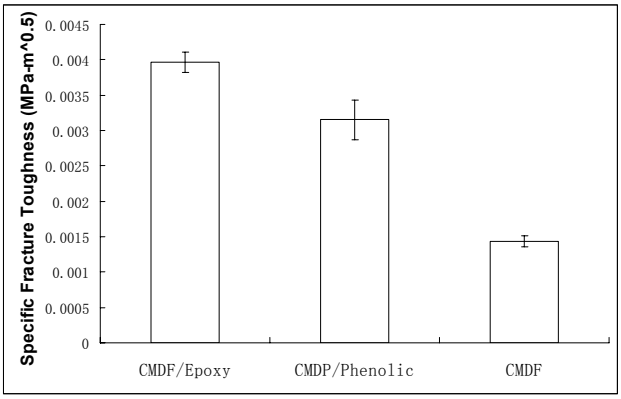

Figure 13. Change of specific fracture toughness after resin infusion.

Conclusions

In this study, CMDF/polymer composites were prepared by vacuum aided resin infusion. The changes of apparent density, pore sizes and distribution, and mechanical properties were studied. It was found that: 1) compared to phenolic resin, epoxy resin was the better option for infusing the porous CMDF to improve its mechanical properties; 2) infusion of resins into the porous CMDF was more efficient in improving its strength than modulus; 3) the increase in bending strength and tensile strength were due to the improved fracture toughness after resin infusion.

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