Composites: Part B 58 (2014) 582–585

Contents lists available at ScienceDirect

Composites: Part B

journal homepage: www.elsevier.com/locate/compositesb

Investigation of correlation between Brinell hardness and tensile strength of wood plastic composites

Alperen Kaymakci [a,1], Nadir Ayrilmis [b,*]

[a] Kastamonu University, Forestry Faculty, Department of Wood Mechanics and Technology, 37000 Kastamonu, Turkey
[b] Istanbul University, Forestry Faculty, Department of Wood Mechanics and Technology, Bahcekoy, Sariyer, 34473 Istanbul, Turkey

ARTICLE INFO

Article history:
Received 31 August 2013
Received in revised form 16 October 2013
Accepted 11 November 2013
Available online 21 November 2013

Keywords:
A: Wood
A: Thermoplastic resin
B: Hardness
D: Mechanical testing

ABSTRACT

The relationship between Brinell hardness and tensile strength of wood plastic composites (WPC) as a function of wood filler content was investigated. The sawdust flour was compounded with polypropylene at 30%, 40% or 50% (by weight) content with and without coupling agent, maleic grafted polypropylene with anhydride, in a twin screw co-rotating extruder. Test specimens were produced by injection moulding process from the pellets dried to moisture content of 1%. The relationship between Brinell hardness and tensile strength for all the filler loading levels was studied using linear regression method. The strong correlation was found between the Brinell hardness and tensile hardness of the WPCs as the filler content was between 30 and 40 wt%. The strong correlation showed that the Brinell hardness could be a good indicator for tensile strength of the WPCs.

1. Introduction

The suitability and end use applications of WPCs are highly related to mechanical and physical properties such as tensile strength, bending strength, impact resistance, hardness, and density of these products. A good understanding of the strength properties of WPCs is of considerable importance for especially semi-structural building products, such as decking, siding, and roofing [1–4]. Along the operating time, semi-structural building products exposed to different types of loading such as compression, hardness, bending and tensile. The ultimate optimization of WPC needs a thorough understanding of material performance and a wide-ranging evaluation of mechanical properties intended for desired applications [1].

As an important property, hardness is of persistent interest to understand the relationships between hardness and other fundamental properties of materials [5]. Because the hardness is a function of the force and size of the impression, the pressure (and hence stress) used to create the impression can be related to both the yield and ultimate strengths of materials [6]. For every material, there is a definite correlation between hardness and ultimate tensile strength [7]. Various correlations have been established between hardness and tensile properties of materials [5,8,9]. Extensive empirical correlations between tensile strength and properties such as hardness and fatigue strength are often quite useful [10]. For many applications of the WPCs such as semi-structural and structural applications, the measurement of tensile strength is needed. However, the tensile strength is more expensive than hardness indentations. Tensile tests are also destructive whereas indentation tests are not (at least for large objects).

Mechanical properties of WPCs have been extensively investigated in previous studies [3,4,11–14]. Most of the studies mainly focused on determining the reinforcing filler types and loading levels, modified fillers, or coupling mechanism on the mechanical properties of WPCs. An extensive literature search did not reveal any information about the correlation between Brinell hardness and tensile strength of WPCs. In this study, we aimed to determine the relationship between Brinell hardness and tensile strength of the WPCs prepared from sawdust flour and polypropylene with and without compatibilizing agent.

2. Experimental

2.1. Materials

Fresh sawdust consisting of a mixture of 50 wt% beech wood and 50 wt% pine wood was obtained from a local carpenter shop in Istanbul, Turkey. First the sawdust was dried in an oven at 60 °C for 10 h to moisture content of 20–30% based on the oven-dry wood weight. The sawdust was then processed by a rotary grinder. The sawdust flour passing through a U.S. 35-mesh screen and was retained by a U.S. 60-mesh screen. The sawdust flour

* Corresponding author. Tel.: +90 212 226 1100/25083; fax: +90 212 226 1113.
E-mail addresses: akaymakci@kastamonu.edu.tr (A. Kaymakci), nadiray@istanbul.edu.tr (N. Ayrilmis).
[1] Tel.: +90 366 280 1702; fax: +90 366 280 1038.

1359-8368/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.compositesb.2013.11.009

was dried in a laboratory oven at 100 °C for 24 h to moisture content of 1–2% and then stored in a polyethylene bag.

Polypropylene (T_m = 160 °C, q = 0.9 g/cm^3, MFI/230 °C/2.16 kg = 6.5 g/10 min) produced by Likom PP Company in Ukraine was used as the plastic material. Maleic grafted polypropylene with anhydride and acid functionality (MAPP, Optim-425) with very high maleic anhydride content (1.6–2.5%) as a coupling agent was supplied from Pluss Polymers Company in India.

2.2. Manufacture of injection molded WPCs

The sawdust flour and the polypropylene with and without MAPP granulates were processed in a 30-mm co-rotating twin-screw extruder with a length-to-diameter (L/D) ratio of 30:1. The raw materials were fed into the main feed throat using a gravimetric feed system. The barrel temperatures of the extruder were controlled at 170, 180, 190, and 190 °C for zones 1, 2, 3, and 4, respectively. The temperature of the extruder die was held at 200 °C. The extruded strand passed through a water bath and was subsequently pelletized. The pellets were stored in a sealed container and then dried (0–1%) for about 3–4 h before being injection molded.

The temperature used for injection molded specimens was 170–190 °C from feed zone to die zone. The specimens were injected at injection pressure between 4 and 5 MPa with cooling time about 30 s. Finally, the specimens were conditioned at a temperature of 23 ± 2 °C and relative humidity of 50 ± 5% according to ASTM D 618 [15]. The compositions of the WPCs are presented in Table 1. The densities of WPCs ranged from 0.98 to 1.04 g/cm^3.

2.3. Determination of mechanical properties

The tensile tests were conducted in accordance with ASTM D638 [16] using a Lloyd testing machine at a rate of 5 mm/min crosshead speed. Twenty injection molded specimens were used to determine the tensile strength each type of WPC. Brinell hardness of the WPCs was measured according to EN 1534 [17] using Llyod testing machine. The measurements were done using a steel ball of 10 mm diameter and load of 3 kN. It took 15 s to reach the maximum load of 3 kN; the load was maintained for 25 s, and then the load gradually decreased to zero within 15 s. The diameter of the remaining indentation opened through the sphere was measured with a Brinell microscope. Twenty injection molded specimens were tested to determine Brinell hardness of each type of WPC.

2.4. Statistical analysis

An analysis of variance, ANOVA, was conducted ($p < 0.01$) to evaluate the effect of the sawdust flour content on the Brinell hardness and tensile strength of WPCs. Significant differences among the average values of the WPC types were determined using Duncan's multiple range tests. The linear regression analysis for the relationship between the Brinell hardness and tensile hardness of WPCs as a function of sawdust flour content was performed.

Table 1
Compositions of the unfilled and filled WPCs.

WPC type	WPC composition		
	Sawdust flour (wt%)	Polypropylene (wt%)	Coupling agent (MAPP) (wt%)
A	30	70	–
B	40	60	–
C	50	50	–
D	30	70	3
E	40	60	3
F	50	50	3

3. Results and discussion

3.1. Tensile strength

The results of tensile strength of WPCs with and without the MAPP are presented in Table 2. The tensile strength of the WPCs increased with increasing sawdust flour content up to 40 wt% but further increment in the filler content decreased the tensile strength. The reduction in the tensile strength of the WPCs beyond 40 wt% sawdust flour was mainly attributed to the poor compatibility between polar sawdust flour and nonpolar polypropylene, which formed the weak interfacial regions. As the sawdust flour was incorporated into the WPC, incompatible interfacial regions between the sawdust flour and polypropylene were created. The weak interfacial regions result in the reduction in the efficiency of stress transfer from the polymer matrix to the reinforcement component [3,4]. However, the incorporation of MAPP into the formulation increased gradually the tensile strength of the WPCs. This improvement is mainly due to ester bonds between the MAPP and wood flour. MAPP has anhydride carbonyl groups, which are susceptible to react with the of hydroxyl groups of the wood [18].

3.2. Brinell hardness

The Brinell hardness values of the WPCs are presented in Table 2. The Brinell hardness values of the WPCs significantly increased with increasing sawdust flour content. This was good consistent with previous studies [19,20]. As the content of the sawdust flour increased from 30 to 40 wt%, the increment in the Brinell hardness was not significant. However, further increment in the sawdust flour content significantly increased the Brinell hardness of the WPC. As the filler content was kept constant, the WPCs without MAPP had lower Brinell hardness value than the WPCs with MAPP. For example, at the constant content of the sawdust flour (50 wt%), the average Brinell hardness value of the WPCs with MAPP was found to be 148.93 HB while it was 137.07 HB for the WPCs without MAPP. The incorporation of MAPP into the WPC increased the Brinell hardness values of all the WPCs because the MAPP improved the interfacial adhesion between the plastic and wood, leading to less micro-voids and filler-polypropylene debondings in the interphase region. The addition of coupling agent increases the ester linkages between the hydroxyl groups of sawdust flour and the anhydride part of MAPP [21].

Table 2
Tensile strength and Brinell hardness of the WPCs.

WPC type[a]	Density (g/cm^3)	Mechanical properties	
		Tensile strength (MPa)	Brinell hardness (HB)
A	0.98 (0.02)[b]	24.04 (2.48) ab[c]	102.27 (15.25) a
B	0.99 (0.01)	27.28 (2.50) c	113.20 (10.00) a
C	1.02 (0.02)	22.25 (2.15) a	137.07 (11.55) bc
D	1.00 (0.02)	26.92 (1.81) bc	109.67 (12.15) a
E	1.01 (0.04)	32.51 (3.30) d	127.40 (12.45) b
F	1.04 (0.01)	25.76 (4.44) bc	148.93 (18.53) c

[a] See Table 1 for WPC formulation.
[b] The values in the parentheses are standard deviations.
[c] Groups with same letters in column indicate that there is no statistical difference ($p < 0.01$) between the samples according. Duncan's multiply range test.