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DETERMINATION OF THE RELATIONSHIPS BETWEEN BRINELL HARDNESS AND TENSILE STRENGTH OF WOOD PLASTIC COMPOSITES

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Abstract:
In this study, we evaluated the relationships between Brinell hardness and tensile strength of polymer composites filled with carpentry wastes (CW) flour. To meet this objective, The CW flour was compounded with polypropylene at 30, 40 and 50% (weight) content with and without coupling agent in a twin screw corotating extruder and then were manufactured by injection moulding process. The relationships between Brinell hardness and tensile strength for all filler loading were studied using linear regression methods. At the same time flexural strength (MOR) and modulus of elasticity (MOE) were determined. The result showed that, regardless of the filler loading, all the relationships between Brinell hardness and tensile hardness of polymer composites filled with CW flour were significant.

Key words: *polymer composite; tensile strength; Brinell hardness.*

INTRODUCTION

As a result of a growing awareness of the interconnectivity of global environmental factors, principles of sustainability, industrial ecology, ecoefficiency, and green chemistry and engineering are being integrated into the development of the advanced materials, products, and processes (Mohanty *et al*. 2005) Composite materials, especially wood plastic composites very suitable for this intention. Basically wood plastic composites are produced by mixing wood flour or fiber such as wheat straw, hemp fiber or carpentry wastes and virgin/ recycled plastics such as polypropylene (PP), polyethylene (PE) or polystyrene (PS) to produce an advanced material that can be processed like a conventional plastic techniques such as extrusion and injection molding. This new material had the appearance and qualities of the rarest species of wood while offering a truly eco-friendly alternative, and met with instant success (Anon 2010). When compared to solid wood materials, wood plastic composites exhibit different physical, mechanical and thermal properties. Strength and stiffness are generally influenced with increased of levels of wood fillers dependent on the materials and manufacturing methods (Wolcott and Englund 1999). By this way, we can say that mechanical performances of wood plastic composites can directly correlated with levels of wood filler, material type and processing method. Strength values are critical designing and evaluating materials for most any application. A good number of researchers determined influence of wood fillers ratio and processing method on the strength properties such as tensile, flexural and elongation of wood plastic composites. As yet there have not been any reports on relationship between tensile strength and Brinell hardness of wood plastic composites. The goal of this study was to investigate the relationship between tensile strength and Brinell hardness of wood plastic composites filled with carpentry wastes using different levels.

EXPERIMENTAL

Materials
Carpentry Wastes

The carpentry wastes were supplied from a carpenter in Sariyer, Istanbul, Northwestern, Turkey. The carpentry wastes were first dried in a laboratory oven at 60°C for 10h. Following the drying, the raw material was processed by a rotary grinder. Finally, it was passed through a U.S. 35 mesh screen and was retained by a U.S. 80 mesh screen. The carpentry wastes flour (CWF) was then dried in a laboratory oven at 100°C for 24 h to a moisture content of 1 to 2%.

Polymer Matrix and Coupling Agent

The polypropylene (MFI/230°C/2.16kg = 5.5g/10min, melting point: 161°C) produced by Likom PP Corporation in Ukraine, was used as the polymeric material. The coupling agent, maleic anhydride-grafted polypropylene (MAPP-Optim-425, MFI/190°C, 2.16kg = 120g/10min), was supplied by Pluss Polymers Pvt. Ltd. in India.

Preparation of Injection Molded PP Composites

The CWF, polypropylene, and MAPP granulates were processed in a 30mm co-rotating twin screw extruder with a length-to-diameter (L/D) ratio of 30:1. The barrel temperatures of the extruder were controlled at 170, 180, 185, 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 to the moisture content of 1 to 2% in a laboratory oven before the injection molding. The temperature used for injection molded specimens was 180 to 200 °C from feed zone to die zone. The thermoplastic composite specimens were injected at injection pressure between 5 to 6MPa with cooling time about 30s. Finally, the specimens were conditioned at a temperature of 23°C and relative humidity (RH) of 50% according to ASTM D 618. The raw material formulations used for the PP composites are presented in Table 1.

Table 1

Compositions of the Unfilled and Filled PP Composites

Composite Type	Composite Composition		
	Carpentry Wastes Flour (CWF)	Polypropylene	Coupling Agent (MAPP)
A	30	70	-
B	40	60	-
C	50	50	-
D	30	70	3
E	40	60	3
F	50	30	3

Determination of Mechanical Properties

The flexural tests were conducted in accordance with ASTM D 790 using a Lloyd testing machine at a rate of 1.3mm/min crosshead speed. Dimensions of the test specimens were 3.5mmx13.2mmx128mm. The tensile tests were conducted according to the ASTM D 638. Tensile specimens (dogbone shape (type III)) were tested with a crosshead speed of 5mm/min in accordance with ASTM D638. In order to measure the Brinell hardness of each type of PP composites were used total twenty specimens for each type of composites. Brinell hardness of the composites was measured according to EN 1534 (2000) using Llyod testing machine. The measurements were done using a stell ball of 10mm diameter and load of 3kN. It took 15 seconds to reach the maximum load of 3kN; the load was maintained for 25 seconds, then within 15 seconds the load gradually decreases to zero. The diameter of the remaining indentation opened through the sphere was then measured with a Brinell microscope.

Statistical Analysis

Analysis of variance (ANOVA) ($p<0.01$) was used to determine the effect of CWF content on selected mechanical of the PP composites using SPSS statistical package program. Significant differences among the average values of the CWF- PP composite types were determined using Duncan's multiple range tests. Relationships between tensile strength and Brinell hardness were determined using standard linear regression methods.

RESULTS AND DISCUSSION

Tensile strength, flexural strength and Brinell hardness values of the polypropylene composites with and without the CWF are presented in Table 2. The air-dry density of the composites ranged from 0.97 to 1.04g/cm^3.

Table 2

Some mechanical properties of the PP composites filled with CWF

Composite type[1]	Mechanical properties				
	Flexural strength (MPa)	Flexural modulus (MPa)	Tensile stregth (MPa)	Tensile modulus (MPa)	Brinell harness (HB)
A	42.08 **(2.82)**	3259.63 **(224.83)**	24.04 **(2.48)**	4078.7 **(170.8)**	102.27 **(15.25)**
B	38.45 **(4.13)**	3642.80 **(370.29)**	27.28 **(2.50)**	4341.1 **(106.7)**	113.20 **(10.00)**
C	32.78 **(3.71)**	4135.45 **(184.23)**	22.25 **(2.15)**	4844.8 **(80.4)**	137.07 **(11.55)**
D	45.28 **(4.99)**	3414.87 **(229.17)**	26.92 **(1.81)**	4064.4 **(66.7)**	109.67 **(12.15)**
E	41.76 **(4.73)**	3941.72 **(379.78)**	32.51 **(3.30)**	4623.6 **(414.6)**	127.40 **(12.45)**
F	35.39 **(2.09)**	4309.41 **(440.74)**	25.76 **(4.44)**	5126.7 **(352.2)**	148.93 **(18.53)**

[1]See Table 1 for composite formulation.

Flexural properties

The flexural strength and modulus values of the CWF - filled polypropylene composites are presented in Table 2. As the CWF loading increased, the flexural strength values of the polypropylene composites with and without MAPP decreased. The flexural modulus of the samples increased by 26% as the CWF increased from 30 to 50wt%, where the flexural strength decreased by 31%. The degree of crystallinity of polypropylene fiber is generally between 50% and 60% (53% for the polypropylene used in the present study) and between 60% and 70% for cellulose. Due to higher crystallinity of cellulose, it is stiffer than polypropylene. The increase in the modulus suggests an efficient stress transfer between the polymer and filler. At similar filler loading, the PP composites without MAPP had lower flexural strength value than the ones with MAPP. For example, at the constant content of the CWF flour (50wt%), the flexural strength value of the PP composites with MAPP was found to be 35.39N/mm^2 while it was found to be 32.78N/mm^2 for the ones without MAPP. The MAPP improves the interfacial adhesion between hydrophilic lignocellulosic filler and hydrophobic polymer matrix, leading to less micro-voids and fiber-polyethylene debondings in the interphase region (Ayrilmis *et al*. 2013).

Tensile Strength

The results of the tensile strength and modulus of the CWF -filled samples with and without MAPP are presented in Table 2. The results of the tensile modulus test were similar to the results of the flexural modulus test; the composites with high CWF content and treated with the MAPP had better flexural modulus than the untreated ones. All the polypropylene composites filled with CWF flour showed higher bending modulus than the neat polypropylene, which was 1250MPa. When compared with the neat polypropylene, the tensile modulus was increased by 310% by adding 50wt% CWF flour to the polypropylene. The tensile strength of the samples increased from 24.04 to 27.28MPa as the CWF increased from 30 to 40wt%. This result was consistent with the results of previous studies. For example, in a previous study, it was observed a similar trend with wood flour filled polypropylene composites. They also reported that dissimilarities between polar wood flour and nonpolar polymer matrix caused poor adhesion and resulted in lower tensile strength (Kaymakci and Ayrilmis 2012).

Brinell hardness

The Brinell hardness values of the PP composites filled with CWF are presented in Table 2. The Brinell hardness values of the composites significantly increased with increasing CWF content. As shown in Table 2, the Brinell hardness of the filled PP composites was higher than that of the neat polypropylene composite which was 48.8HB. This result was good consistent with previous studies (Kord 2011, Radojević *et al*. 2006, Kaymakci *et al*. 2013). At similar filler loading, the PP composites without MAPP had lower Brinell hardness value than the ones with MAPP. For example, at the constant content of the CWF flour (50wt%), the Brinell hardness value of the PP composites with MAPP was found to be 148.93HB while it was found to be 137.07HB for the ones without MAPP.

Determination of the relationships between Brinell hardness and tensile strength

The relationship between Brinell hardness and tensile strength correlations of the PP composites filled with CWF are presented in Fig. 1, 2 and 3. Among the all studied correlations, as expected, the highest coefficient of correlation was found between Brinell hardness and tensile strength of the PP composites filled with CWF.

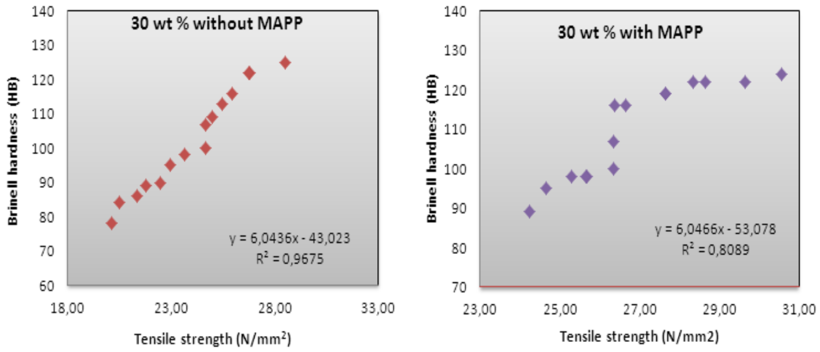

Fig. 1
The relationship between Brinell hardness and tensile strength correlations of the PP composites filled with CWF (30wt %).

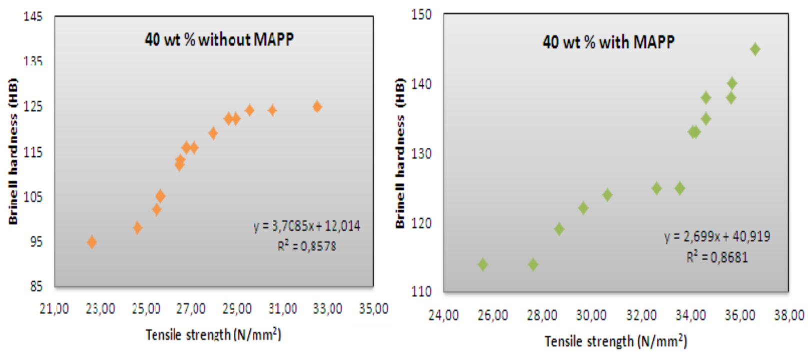

Fig. 2
The relationship between Brinell hardness and tensile strength correlations of the PP composites filled with CWF (40wt %).

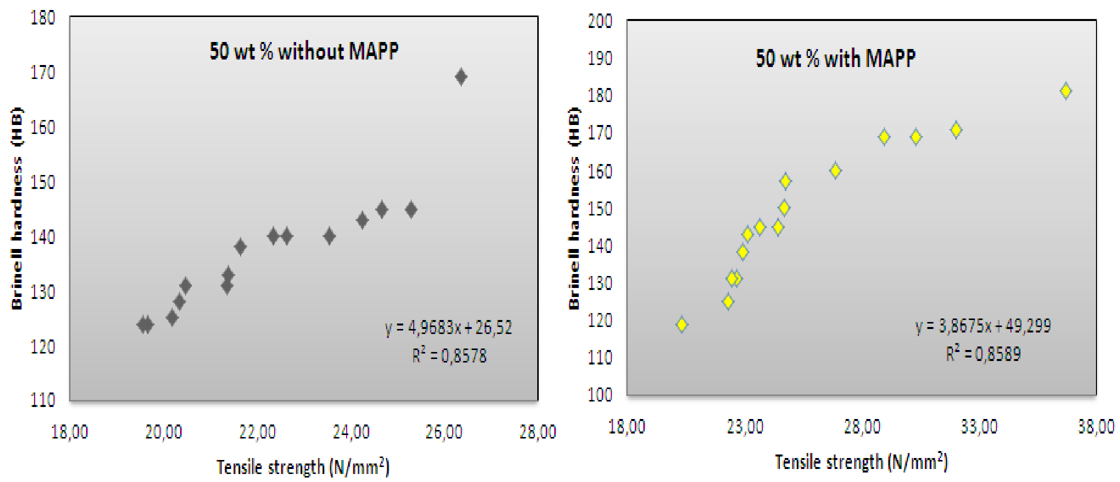

Fig. 3
The relationship between Brinell hardness and tensile strength correlations of the PP composites filled with CWF (50wt %).

CONCLUSION

The results of the present study have shown that regardless of the filler loading, all the relationships between Brinell hardness and tensile hardness of polymer composites filled with CWF flour were significant. The tensile and flexural strength of PP composites decreased with increasing CWF loading. But all the polypropylene composites filled with CWF flour showed higher bending and tensile modulus than the neat polypropylene. Adding the MAPP significantly improved the tensile, flexural and hardness properties of the filled polypropylene composites.

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