MATHEMATICAL APPROACH TO VERIFY POWER LAW EQUATION AS CONSTITUTIVE EQUATION FOR WOOD-PLASTIC COMPOSITES

Nathan J. Jam[1], **Mohammad Golzar**[2] **and Amir H. Behravesh**[2]

1. Department of Mechanical Engineering, Pardis branch, Islamic Azad University, Tehran, Iran
2. Department of Mechanical Engineering, Tarbiat Modares University, PO Box 14115-111, Tehran, Iran

Introduction

A wide range of composites containing different polymeric materials, with wood fillers are known as Wood-Plastic Composites (WPC)[1]. Adding wood particles to plastics causes different effects on the resulted composite such as stiffening the products with a reduced toughness [2]. Most of research works on WPC have been carried out on mechanical properties such as tensile strength, impact strength, modulus of elasticity (MOE) and modulus of resilience (MOR) [3-5].

In commercial products, WPCs are produced with relatively high contents of wood, e.g. about 50 and 60 wt%, which is close to its maximum packing content [6]. A review of literatures shows that the reported rheology studies on the highly filled wood plastic composites are scarce. Due to the low contents of wood in the studied composites, little basis is provided for applying their data into commercial process of WPC [6]. There is no clear theoretical basis for the melt flow mechanism of WPCs.

Extensive works have been carried out to report the effect of wood component on the final properties of WPC [3-5]. On the other hand, usage of recycled material in WPC is a bonus. Fine wood particles, produced by sanding process, is a very attractive and promising source as wood component.

In the way of modeling and analyzing the WPC flow behaviors; there is a need to measure shear stress versus shear rate. In the oscillatory shear experiments, the results are functions of frequency. In the first part of this research work, flow behaviors of the composites produced with the fine particles and HDPE as the polymer matrix, have been investigated. In the second part, some proposed methods were evaluated and compared with each other.

Experimental

Materials

High density polyethylene (HDPE), grade I2, with MFI of 8.1 g/10min (190ºC / 2.16 kg) was used as the polymeric material. Wood flour, with mesh size of 270, a byproduct of sanding process, was used as the wood component material.

Theory

For modeling the flow, power law model was employed in three different views. The general equation for power law is [7]:

$$\tau = k\,.\,\dot{\gamma}^{n} \tag{1}$$

Method 1: Using the shear stress versus frequency

According to the following equation, it is possible to calculate the shear rate form the frequency and shear strain [7].

$$\dot{\gamma} = \gamma\,.\,\omega \tag{2}$$

In this method, shear stress versus frequency can be simply changed into shear stress versus shear rate ($\tau(\omega) \rightarrow \tau\,(\dot{\gamma})$).

Method 2: Using complex viscosity versus frequency

In this method, the Newtonian fluid equation was employed (Equation 3 [7]).The complex viscosity (η^*) was assumed to be equal to the viscosity of the composites. By this assumption the relation between the shear stress and shear rate can be proposed simply as Equation 4.

$$\tau = \eta.\dot{\gamma} \tag{3}$$

$$\tau = \eta^{*}.\dot{\gamma} \tag{4}$$

Method 3: Using dynamic viscosity versus frequency

The basic assumption in this method is as given in Method 2, except that dynamic viscosity (η') was used instead of complex viscosity in the Newton's equation (See Equation 5). The dynamic viscosity is obtained from the loss modulus according to Equation 6 [7].

$$\tau = \eta'.\dot{\gamma} \tag{5}$$

$$\eta' = {G"}/{\omega} \tag{6}$$

Measurement

Dynamic oscillatory measurement has been established as the most reliable method for evaluating rheological properties of the filled polymers [8]. Influence of wood flour content on the rheological properties of the composites was investigated versus angular frequency to obtain the data used for evaluating the flow behavior of the composites. Storage modulus (G'), loss modulus (G"), and complex viscosity (η^*) were thus measured [9].

Results and Discussion

Via data processing of the used rheometer instrument, it is possible to obtain the shear stress values versus frequency from the experiments. As the first step, Method 1 was applied to obtain shear stress versus shear rate. After calculating shear rate according to Equation 2, and following the procedure of Method 1, the graphs of shear stress versus shear rate (Figure 1) was obtained.

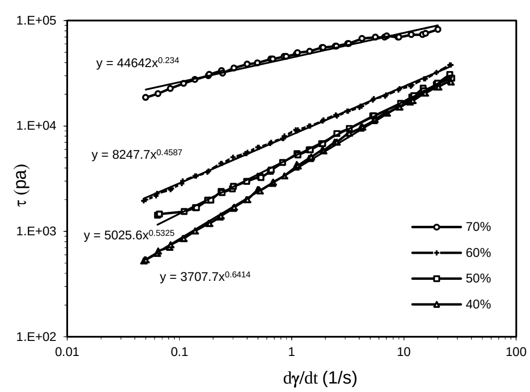

Fig. 1 Shear stresses versus shear rate according to Method 1

As mentioned in Methods 2 and 3, by using complex and dynamic viscosities, respectively, instead of viscosity in the Newton's equation, the shear stress would be obtained versus shear rate. The results are shown in Figures 2 and 3, respectively.

Table 1 gives the variables of power law equations of the composites for all three methods. As it can be seen, although the power law and consistency indexes in these methods are different with each other, the variation of shear stress versus shear rate nearly obeys the power law equation in all cases.

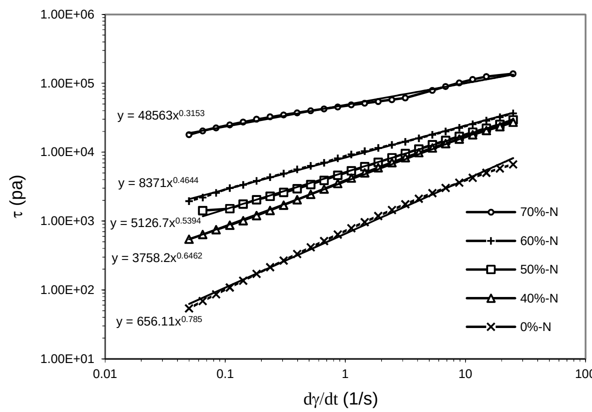

Fig. 2 Shear stresses versus shear rate according to Method 2

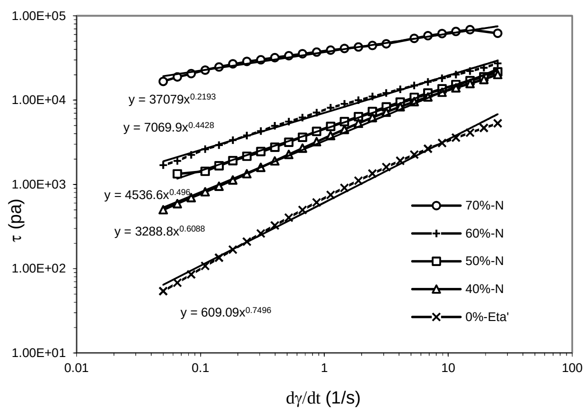

Fig. 3 Shear stresses versus shear rate according to Method 3

Table 1 Comparing the variables of the power law equation for method 1, 2 and 3.

Content of wood (%)	Method 1		Method 2		Method 3	
	k	n	k	n	k	n
0	1000	0.79	700	0.79	600	0.75
40	3700	0.64	3700	0.65	3300	0.61
50	5000	0.53	5100	0.54	4500	0.50
60	8200	0.46	8400	0.47	7100	0.44
70	44600	0.23	48600	0.32	37100	0.22

In Method 1, since the data were obtained directly from the rheometer instrument, they could be more reliable than those of the other methods thus these data can be used as the reference values.

The behavior of the viscosity, complex viscosity and dynamic viscosity versus shear rate are nearly the same but it is not allowed to use one instead of the others. According to the above mentioned results, it can be seen that using dynamic viscosity for the composites with the high contents of wood, results in the consistency and power law indexes values to be closer to those of Method 1; however for the WPCs having low contents of wood using complex viscosity yields closer values to those of Method 1.

One of the possible reasons could be the relation between the elastic behavior of the composite and the content of wood. The higher is the wood content; the lower would be the elastic behavior. The storage modulus decreases and the loss modulus increases, and since the dynamic viscosity is a function of loss modulus, it will play a more important role in characteristic of the composite.

In another similar research with the same material, for the composite containing 40 wt% of wood, the value for power law index (n) was obtained 0.87 [10], which is noticeably high in comparison with other researches [11]. But the results of power law index in the current study for WPCs with different contents of wood are closer to the other reported values [11].

As it discussed in the previous experiment, by decreasing the wood content in the wood-plastic composite, the complex viscosity will give better results in explaining the behavior of the composite.

Conclusions

Flow properties of HDPE-fine wood particle composites (40-70%) were investigated and the power law equation has been used to predict the behavior of the material. The results conclude the followings:

- In frequency sweep measurement, significant changes were observed in storage modulus, loss modulus, and complex viscosity when adding wood content from 60% to 70%.
- For the composites containing low contents of wood, using complex viscosity will yield more reliable values for power law equation.
- For the composites containing high contents of wood, using dynamic viscosity will yield more reliable values for power law equation.

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