DEVELOPMENT OF A THERMOPLASTIC EXTRUSION METER

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Abstract

Thermoplastic recycling is recognized as an important method of waste reduction and it reduces environmental pollution problem posed by non-biodegradable nature of polymers. Quality plastic products can only be made from recycled thermoplastics when the melt characteristics of the material are known. Non-availability of thermoplastic extrusion meter in local plastic industries makes it difficult to ascertain the actual melt mass flow rate of recycled thermoplastics which makes it difficult to verify whether the plastic grade is within the required fluidity range and addition of plasticizers is by trial and error instead of the ISO standard. It's important to develop a thermoplastic flow meter, to determine the melt mass flow rate of thermoplastic materials for quality control in plastic industry in Nigeria. The thermoplastic extrusion meter was designed to ASTM D1238 standard, and the fabrication was made from ANSI 1018 cold rolled mild steel. The equipment was calibrated to ensure actual melt temperature and the performance of the equipment was evaluated. Procedure A was employed to determine the MFR of virgin and recycled HDPE.

[redacted]

KEYWORDS: *Development, extrusion, thermoplastics, temperature, meter.*

The HDPE for virgin was found to be 9.96g/10mins while that of first recycled HDPE was 10.88g/10mins under the same load and temperature conditions of 2.16Kg and 190^{O}C respectively.

INTRODUCTION

Thermoplastics are high performance materials, and they are increasingly replacing the conventional materials such as metal, glass and wood in numerous applications where the combination of mechanical, thermal, electrical and chemical properties is desired[1]. However, plastic materials are non – biodegradable and as such they constitute an environmental hazard since they cannot be disposed-off like other materials. They are inflammable and if burnt they create air pollution [2]. Thermoplastic recycling is recognized as an important method of waste reduction and it reduces environmental pollution problem posed by non-biodegradable nature of polymers. Thermoplastics are widely used for different kinds of household and commercial products ranging from motorcycle helmet visors, aircraft windows, viewing ports of submersibles, and lenses of exterior lights of automobiles.

The quality of a thermoplastic product is a function of the quality of the input materials and the processing conditions. [3] indicated that the mechanical properties of the products depend on the melt temperature, injection pressure, clamping pressure and cooling rate. The selection of these process parameters depends to a large extent on the melt flow characteristics of the particular thermoplastic.

A melt flow meter is particularly important in Nigeria because whole products (black jerry cans of varying capacities) are being made from 100% recycled thermoplastic materials of unknown characteristics. In cases where mixtures of recycled and virgin materials are being used, the plastic flow meter is not available in plastic factories to make it possible to seek a mixture with a flow behaviour that yields acceptable mechanical properties. Quality plastic products can only be made when the melt characteristics of recycled thermoplastics is known. Hence the need to develop a standard melt mass flow meter that can be used for all thermoplastics that are frequently used in Nigeria to ascertain the actual MFR of recycled thermoplastics and verify if the plastic is within the required fluidity range, and to also determine the amount of plasticizers to be added to the recycled thermoplastics.

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MATERIALS AND METHOD

Materials

The major material used in the development of the thermoplastic extrusion meter is ANSI 1018 cold rolled mild steel with the following properties; density is 7850Kg/m^3, Young's modulus 210GPa, ultimate tensile strength 439.6MPa and yield strength 369.99MPa. The thermoplastic material used in this study is HDPE in its virgin and recycled states because of its wide usage both for different kinds of household and commercial products in Nigeria. Heater band and the temperature unit were purchased from electrical store.

Description of Thermoplastic Extrusion meter

The thermoplastic extrusion meter (Figure 1) consists of a heating barrel with a cavity where the resin is charged. The barrel houses the die (an orifice) and piston with set of standard weights placed on the piston head. The barrel is surrounded by two heater bands, followed by fiber glass and all enclosed in a steel cylinder. The heating barrel is mounted on a vertical column via welded bracket as shown in Figure 1. The column is essentially free at the top and fixed at the base.

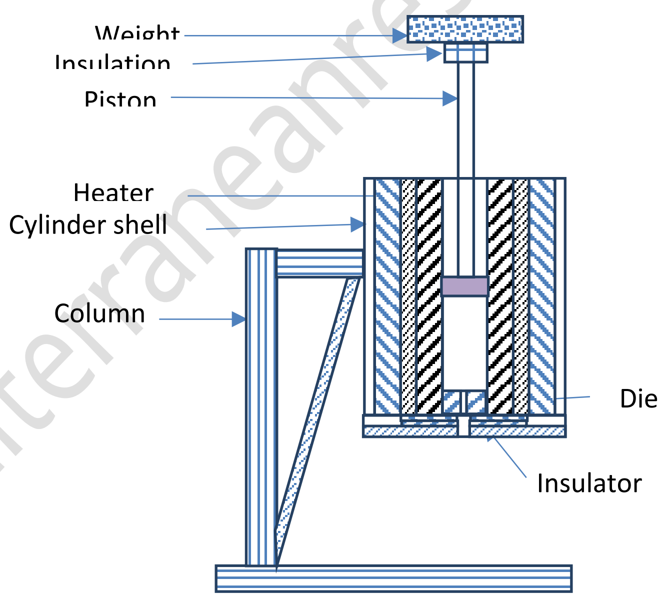


Figure 1: Schematic diagram of thermoplastic extrusion meter.

Design Analysis and Calculation

The ASTM D 1238 standard specified that internal diameter of the barrel should be 9.5504mm ±0.0076mm, outside diameter of barrel: 50mm, barrel height: 115mm to 180mm, die outer diameter: 9.55mm ± 0.005mm, inner diameter: 2.095mm and die height: 8mm ± 0.025mm.

Design of the Heating Barrel

The wall of heating barrel is required to transmit heat to the test material and withstand the pressure required to extrude the thermoplastic at its melting temperature. Though the difference between specified external (50 mm) and internal (9.5 mm) diameters of the barrel is high enough to have made the barrel a thick walled cylinder, the temperature monitoring hole must be relatively close to the plastic melt in order to have an adequate reflection of the melt temperature. in line with [4] the condition of thin walled pressure vessel has been adopted in this work. The tangential stress in thin cylinder wall is given by Equation 1 while the axial stress is given by Equation 2. The tangential stress is the critical stress and is used to determine the critical thickness of the barrel at the point where temperature monitoring hole is inserted.

$$\sigma t = \frac{P.D}{2t} \tag{1}$$

$$\sigma t = \frac{P.D}{4t} \tag{2}$$

Where P is pressure, D is inside diameter of barrel and t is thickness.

The extrusion pressure depends on the specified mass for test thermoplastic. The maximum specified mass is 21.6 kg which is for polyethylene (PEa) [5].The pressure load on the barrel is given by,

$$P = \frac{F}{A} \tag{3}$$

Where F is applied force, A is barrel area.

$$P = \frac{21.6\times 9.81\times 4}{\pi\times d^2} = \frac{21.6\times 9.81\times 4}{\pi\times 0.0095^2}$$

$$P = 2.989\text{Mpa}$$

And because of the thermal effect on the heating barrel; the additional thermal stress is

$$\sigma_2 = E\alpha\Delta T \quad (4)$$

Where E is Young modulus of elasticity of steel, α is coefficient of expansion and ΔT is difference in temperature. For steel,

$E = 210\text{x}10^9$,

$\alpha = 10\text{x}10^{-6}$. Therefore thermal stress is,

$\sigma_2 = 210 \times 10^9 \times 10 \times 10^{-6} \times (190 - 25) = 346.5\text{MN/m}^2$.

However the heater band is fastened to the barrel with mild steel bolt which could expand at about the same rate as the heating barrel. Thus the actual induced thermal stress is only a negligible fraction of the value calculated. Substituting the yield strength for ANSI 1018 cold rolled mild steel into Equation 3 and using a factor of safety as 3 yields,

$$\frac{369.99 \times 10^6}{3} = \frac{2.989 \times 0.0095}{2t}$$

This gives t = 0.1151mm.

Thus the temperature monitoring hole must ensure a thickness of 0.115mm from inside wall of the barrel.

Frame Design

The frame shown in Figure 2 was designed as a short column with a slenderness ratio l/k less than 80 and fixed-free end conditions. The Johnson's straight line formula for short column (Equation 5) was adopted for the design [6]. A rectangular plate was selected for the design shown in Figure 2

$$W_{cr} = A(\sigma_y - C_1(l/k)) \quad (5)$$

Where Wcr is critical load, A is cross sectional area of column, C_1 is a constant, l is length, and k is the least radius of gyration of section. The constant C_1 is defined by Equation 6,

$$C_1 = \frac{2\sigma_y}{3\pi}\sqrt{\frac{\sigma_y}{3CE}} \quad (6)$$

Where σy is the yield strength, C is end fixing coefficient and E is modulus of elasticity.

$C = \frac{1}{4}$ for one end fixed and the other end free

A = ab

Let a = 0.2b

Therefore A = $0.2b^2$

$C_1 = 3.76 \times 10^6$

From Equation (5), and using a factor of safety of 3;

From $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

(7)

= 15.28mm

And since the column is rectangular in cross section, the moment of inertia of the column is; $\sigma = \frac{M}{I}$ at the place where force is applied

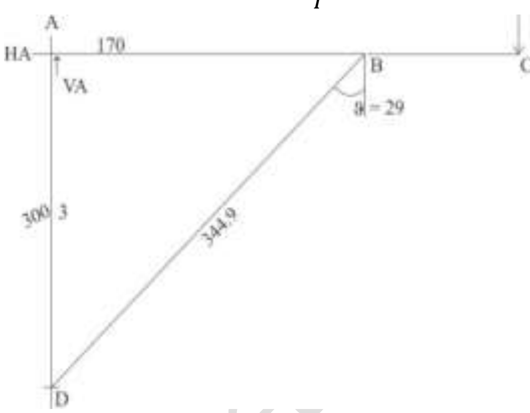


Figure 2: Free body diagram of the frame

To determine forces in members of the frame, moments of forces are taken about point A

H_D x 300 = 365x245

$H_D = \frac{365 \times 245}{300}$ = 298.08N

Moments about D

Joint A

$\sum Fx$ = 0

H_A = 298.08 = F,

$\sum Fy$= 0 = VA = 0

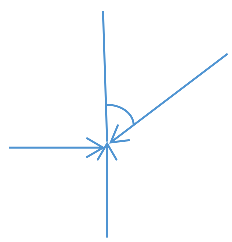
Equilibrium of Vertical forces in frame

$\sum Fy$= 0

$V_D + V_A = 365$

1. $365 = R_{AV} + R_{BV}$

Modeling welded joint at A as simple joint and considering equilibrium of forces at the joint



$365 = R_{AV} – R_{BV}$

In the absence of AC, BC is a cantilever with R_{BV} Moments about C

$365 \times 245 (R_{AV} + R_{BV})$ Rah x 300 = 0

$R_{AV} + R_{BV} = 365$

$\sum Fy$= 0

But $V_A = 0$

$V_D = 365$

Force in member 2

Joint D

$\sum Fy$ =0, F_2 Cos 29.54 – 298.08

$F_2 = \frac{298.08}{\cos 29.54} = 342.70N$

Thus $F_1 = 298N$

$F_2 = 342.70N$

$V_D = 365$

Therefore the Stresses in member 1 and 2 are

$\sigma 1 = \frac{F1}{A1}$

From $A = 0.2b^2$

Therefore $A = 4.5X10^{-5}$

$$\sigma 1 = \frac{298}{4.5\times10^{-5}}$$
$$= 6.62\text{Mpa}$$
$$\sigma 2 = \frac{F2}{A2}$$
$$= \frac{342.70}{4.5\times10^{-5}}$$
$$= 7.6\text{Mpa}$$

FABRICATION AND ASSEMBLY

The developed extrusion plastometer was fabricatated. The major operations were cutting, turning, facing, drilling, welding and bolting. The frame was produced with mild steel flat bar and welded to a flat plate as the base.

Centre lathe was used to machine the heating barrel from a mild steel rod of 60mm diameter to 50mm diameter, 140mm length and a 9.55mm diameter hole was drilled through centrally.

The lagging case (the outer cylinder) was also fabricated using mild steel pipe of 150mm diameter, 140mm length and 5mm thickness.

The piston and the die were also machined from mild steel rods. The steel rod of 25mm diameter and 200mm length was on one end step turned to the head of 9.55mm diameter and 6.5mm length that is the end to be inserted into the heating barrel, while the load carrying end to 20mm diameter, 6mm length and the remaining 187.5mm was reduced to 8mm diameter.

The fabricated extrusion meter parts were assembled thus: The die plate screwed to the heating barrel, the die and piston inserted into the barrel capillary, the heater band mounted on the barrel and the unit mounted on insulation in the outer cylinder, and then the remaining space between them was filled with insulation (fiber glass). The unit was then mounted on the frame and connected to the control unit.

Calibration and Performance Evaluation

Sample Collection and Preparation

The samples of the virgin HDPE material in granulated form were purchased from a local polymer material shop in Kaduna, Kaduna State while the

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recycle HDPE material was obtained by cutting the extruded virgin material. That is, cutting the extrudates (extruded material) after each extrusion into smaller pieces almost the same size as the sizes of the virgin material.

Experimental procedure for MFR measurement

ASTM [7] Standard was employed for the MFR measurement. The equipment and the temperature control unit were switched on; the actual melt temperature of 190^{O}C was correlated to the barrel via thermocouples inserted in a hole drilled in the barrel. The equipment was maintained at this temperature and a pre-heat time of four (4) minutes was allowed prior to charging. After which a minute of charging and load application was allowed. Five grams (5g) of virgin HDPE was charged into the barrel. 2.16kg weight was applied to the piston to force the molten HDPE through a 2mm orifice of the die. The stop watch was used to measure the extrusion time. The extrudates were cut into small sizes almost the same size as the virgin HDPE, collected, and weighed using an electronic weighing balance to determine the mass of the extrudate. MFR values were calculated in g/10mins. The extrusion time, temperature and mass of extrudates were recorded.

RESULT PRESENTATION

Table 1 presents the results for the melt mass flow rate MFR of virgin and recycled HDPE. The MFR for virgin was calculated to be 9.96g/10 minutes which falls within the range of 2.2 to 22g/10mins provided by the manufacturer. The effectiveness of using the developed plastic melt flow meter for characterizing the input materials for thermoplastic production has been established.

Table 1: presentation of MFR for virgin and recycled HDPE

S/NO	Material	Extrusion time (Secs)	Extrusion Temperature (^{O}C)	Force (N)	MFR (g/10mins)
1	Virgin	283	190	21.6	9.96
2	1st recycle	270	190	21.6	10.88

3	2nd recycle	256	190	21.6	11.25
4	3rd recycle	247	190	21.6	11.90
5	4th recycle	235	190	21.6	12.26

CONCLUSION

The development of a thermoplastic extrusion meter for the determination of melt mass flow rate of different thermoplastic materials was successfully carried out in this work. The equipment was used to determine the MFR of both virgin and recycled HDPE. The HDPE virgin material was recycled for five times and at each recycle, the MFR was determined. An increase in each recycle indicates that recycling has effects on the MFR of the material. It shows that plastic industries using recycled materials need the melt flow meter for monitoring the behaviour of production input materials.

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