Design of Fiber Feeding Mechanism for Direct Extrusion Compression Moulding of Natural Fiber Thermoplastic Composite

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***Abstract*—Twin screw extruders has been used for many years to compound all types of fibers into plastic to enhance mechanical properties of final product .In recent years has been a growth in the use of long fiber technology to manufacture stronger and lighter quality parts, particularly for automotive and construction markets.**

Extrusion compounding addresses such as the non-homogeneity of the mixture and separation of fiber from matrix during the processes, which consequently affect the mechanical and physical properties of the resulting composites. The present study is focused on design of fiber feeding mechanism for manufacture of long natural fibres reinforced thermoplastic in direct extrusion compression moulding.

For our study, rectangular profiles were extruded using a twin-screw extrusion system with polypropylene and maleated polypropylene(MAPP) coupling agent with varying length of natural fibre to investigate their effects on thermoplastic processing and mechanical properties. Work has been done to redesign the extrusion system setup to achieve smoother and stronger profiles. This system forces the materials to flow in one direction to achieve higher net alignment of fibres during sample preparation, which is the case during extrusion

INTRODUCTION

In the plastics industry, there are three main extruder types: the screw extruder, which is the most common, the ram extruder, and the drum or disk extruder, which is the least common. In a screw extruder, a screw rotates in a cylinder; the rotation of the screw creates a pumping action.

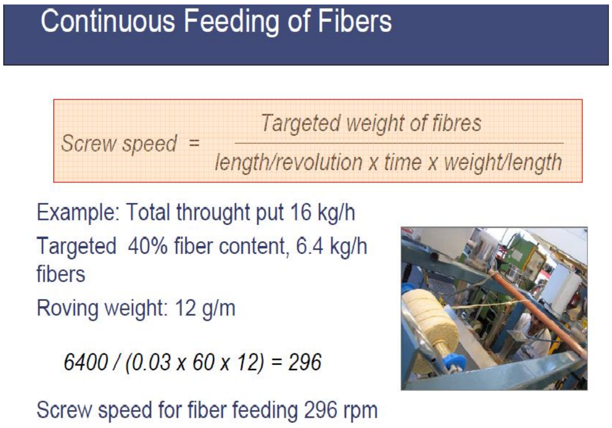
A screw extruder can have one screw or more. An extruder with one screw is called a single screw extruder it is the most common machine in the plastics processing industry. An extruder with more than one screw is called a multi-screw extruder, the most common of which is the twin-screw extruder (which has two screws). There are several types of twin-screw extruders. In most twin-screw extruders, the screws are located side by side. If both screws rotate in the same direction, the extruder is called a co-rotating twin-screw extruder. If the screws rotate in opposite directions, it is called a counter rotating twin-screw extruder. Twin-screw extruders can run at high or low speed, depending on the application. High-speed extruders run at approximately 200-500 rpm or higher; they are primarily used in compounding. Low speed extruders run at approximately 10-40 rpm and are used mostly in profile extrusion applications. Most twin-screw extruders for profile extrusion are counter-rotating extruders. This is because counter-rotating extruders tend to have better conveying characteristics than co-rotating extruders. Most twin 23 screw extruders have parallel screws, but some extruders have conical screws where the screws are not parallel. Another distinguishing feature of twin extruders is the extent that the screws intermesh. The screws can be fully intermeshing, partially intermeshing or non-intermeshing. Most twin-screw extruders are intermeshing. The advantage of non-intermeshing extruders is that they can have a very long length without problems with respect to metal-to metal contact between the screws. The length to diameter ratio (L/D) can be 100:1 or higher. The L/D of intermeshing twin-screw extruders is generally limited to values less than 50:1. A disadvantage of current non-intermeshing twin screws is that they have limited dispersive mixing capability. Mixing takes place both in the melting zone as well as in the melt conveying zone of the extruder. The solid plastic typically moves in plug flow, which means that there is no relative motion between the solid plastic particles. As a result, there is little or no mixing in the solids conveying zone. This means that complete mixing does not start until all the plastic has melted (Rauwendaal, 1998).

Extrusion Parameters

Extrusion engineers identify five factors that limit product throughput an quality:power/screw speed, temperature, feed, vacuum, and downstream processing (Hanawalt, 2002).

Screw speed:

Screw speed must be maintained at a high rate in order to minimize residence time and maximize throughout. However, when a product is heat sensitive (as flax fibers are), extruder screw speed is limited by the maximum shear rate that the product can experience without degradation (Hanawalt,2002). Another reason for limiting screw speed is to avoid air entrapment and to prevent excessive melt temperatures. If the polymer is extruded at rates thatare too high, air entrapment can occur, resulting in tiny bubbles in the extrudate (Cisneros, 2002).



Temperature:

Temperature limitations in extrusion result from either the inability to add enough heat to get a consistent melt (130.34°C for LLDPE with silane treated fibers and 133.38°C for HDPE with silane treated fibers) (Wang, 2004) or the inability to remove enough heat from a melt to prevent product degradation(200-220°C for flax fibers) (Composite Materials Group, 2001; Powell et al.,2002; Wielage, et al., 1999). Flax fibers are heat sensitive. If the barrel temperatures and/or the screw speed are very high, it is possible to make a product consisting of plastic and degraded fiber. This scenario results particularly when the melting point of a polymer is higher than the degradation temperature of the fiber. Thus, the melting point of the matrix should be lower than the degradation temperature of the fibers to prevent fiber degradation (Hanawalt, 2002).s

Table1. Overview of the process parameters used for compounding of PP/sisal method C.

Temperature of different zones in the barrel (°C) Die (°C) Speed (rpm) Torque (%)

T1 T2 T3 T4 T5 T6 T7 T8 T9 T10

PP 195 200 200 200 200 200 200 200 210 220 100 60

Screw configuration

Ts 5*t 3*kt1 tneg 3*t 3*kt2 tneg 4*t kt1 kt2 tneg 3*t 2*tt 2*t

where ts¼small transport element 25 mm, t¼ transport element 36 mm, tt¼ transport element with teeth 20mm, tneg¼ negative transport element, kt1¼ kneading element 36mm, kt2¼ kneading element 24 mm.

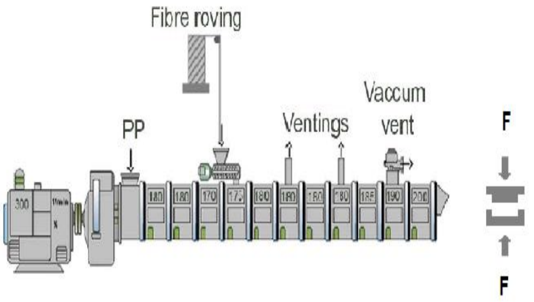


Image 1: Barrel zones

LITERATURE SURVEY

1.) Sombatsompop and Panapoy (2000) investigated the effect of screw speed on two dimensional temperature profiles of flowing polypropylene melt in the barrel of a counter-rotating twin screw extruder using a designed experimental apparatus and a thermocouple temperature sensing device, the 29 experimental apparatus being connected to a high speed data logger and a computer. The flow patterns of the polymer melt in the barrel of the extruder were also revealed. Changes in melt temperature profiles with extrusion time were discussed in terms of the flow patterns of the polymer melt during the flow, the increase in melt temperature being closely associated with total flow length of the melt and shear heating and heat conduction effects.

2.) Steward and Bradley (1991) studied the extrusion characteristics of various screws used to process PP. The influence of various extrusion variables such as screw type, extruder diameter, length to diameter ratio, temperature profile and screw speed on the degradation of the material as seen through the melt flow rate (MFR) increase of PP was examined. It was shown that some of the findings will allow improved extrusion parameters to the producer desiring minimized property reductions of the PP being used. The performance trends measured from these two PP materials should be useful over a wider range of MFR levels.

3. Charlie martin studied twin screw extrusion systems for direct long fiber profile extrusion.

Twin screw extruders have been used for many years to compound all types of fibers into plastics to enhance mechanical properties of the final product. In recent years, there has been a growth in the use of long fiber technology to manufacture stronger and lighter parts, particularly for the automotive and construction markets.

TWIN SCREW EXTRUDER DESIGN FOR LONG FIBER PROCESSING

In a twin-screw extruder, the motor rotates the screws to impart shear and energy to the product. The gearing reduces the motor speed to the desired screw rpm while multiplying torque and the distribution gear maintains the angular timing of the two screws and absorbs the thrust load from the screw set. Process control parameters include screw speed (rpm), feed rate, temperatures along the barrel and die, and vacuum level. Readouts typically include melt pressure, melt temperature, motor amperage, and specific energy consumption.

For any twin-screw extruder, the same basic process functions are performed, namely feeding, melting, mixing, venting, and developing die and localized pressure. All of these unit operations are required to produce a long fiber product, whether it is a pellet, extrudate, or eventually a molded part. For any of these systems, the twin-screw process section is similar. The first 2/3 of the machine system can be configured for compounding and devolatilization. The fiber rovings are introduced into a melt stream, and from this point onward distributive mixing, devolatilization, and pressure stabilization are performed as required to provide a usable melt stream to the downstream process.

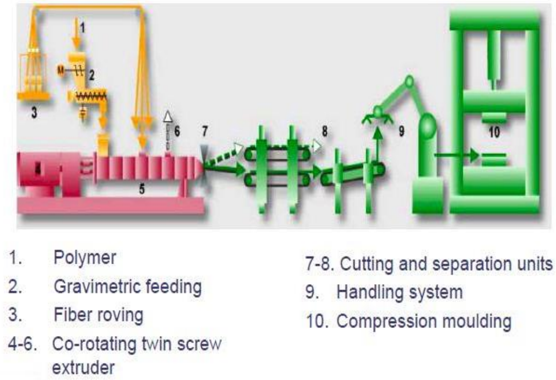


Image 2: Feeding of long fibers into the extruder

A common term used in extrusion is length to diameter ratio, or L/D. This is the length of the screw divided by the diameter. For instance, an extruder that is 3000 mm long with a 75-mm-screw diameter has a 40:1 L/D. Typical extrusion process lengths are in the 28:1 to 44:1 L/D range, depending upon the number of process tasks to be performed, and are typical for long fiber products. Twin-screw extruders use segmented screws that are assembled on splined and hammered shafts. The modular barrel sections are electrically heated and cooled by liquid, using cooling bores inside the barrel and close to the melt stream to prevent material degradation and to maintain the desired melt viscosity within the process section.

Abrasive wear in a twin-screw extruder is localized in the extruders solids-conveying and mixing sections. To resist wear, vanadium carbide modifications of steels are widely used for screw elements and kneading blocks. To simultaneously resist corrosion and wear, as may be needed for processing natural fibers, many approaches are used, including the use of nickel-based alloys. Barrels can use tungsten carbide inlays to provide the highest resistance to wear. For a large number of applications, a standard workhorse material of construction for screws and kneading blocks is through-hardened D2 tool steel. For long fiber processing, particular attention must be paid to the metallurgies after the introduction of the long fiber into the process. Managing the shear stress within the process section can be as important as the choice of metallurgies to combat wear.

The bi-lobal corotating twin-screw extruder is the industry standard for long fiber compounding. The screws are termed self-wiping, and the material follows a figure eight pattern down the length of the screws. There are seemingly an infinite number of screw design variations possible. There are, however, only three basic types of screw elements: flighted elements, mixing elements, and zoning elements. Flighted screws forward material past barrel ports, through mixers, and out of the extruder. Zoning elements isolate two operations within the extruder. Screws can be made shear intensive or passive, based upon the elements used in the design. Accordingly, the twin-screw extruder can perform dispersive mixing early in the process for wide ranging formulations, with the latter portion of the process length being dedicated to long fiber mixing/devolatization.

Mixing elements may be dispersive or distributive. The wider a kneading element is, the more dispersive it becomes as elongational and planar shear effects occur when materials are forced up and over the land. Narrower kneading elements are more distributive in nature with high melt division rates and significantly less elongational and planar shear. Distributive mixing elements allow melt divisions with little extensional shear, which can be particularly useful for mixing heat- and shear-sensitive materials.

Preserving fiber lengths results in optimum physical properties of the final part but is a balancing act. If bundles are not well opened, the fibers will be long, but physical properties will be poor because the fibers are not wetted. If fibers are pulled out of bundles and are well wetted, the process of extracting and wetting may also cause excessive breakage.To produce gentle wetting and fiber bundle opening, the rovings are strategically exposed to primarily distributive mixing to obtain the proper fiber length .

The pressure gradient in the twin-screw extruder is determined by the selection of screws. The feeders set the throughput rate, which is entirely independent from extruder screw rpm. Flighted elements are placed strategically so that the screw channels are not entirely filled underneath vent/feed sections, which facilitates downstream feeding of fibers and prevents vent flooding.

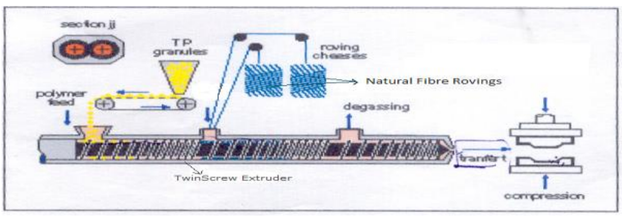


Image 3: Feeding mechanism

Twin-screw extruders are also highly efficient at performing devolatilization. Design factors that affect devolatilizing efficiency are residence time under the vent or vents (longer is better); surface area of the melt pool (higher is better); and surface renewal (higher is better).Vents in the twin-screw extruder can be sequenced to facilitate devolatilization before and after the introduction of the fiber. A back vent is typically adequate for removal of surface moisture inherent with glass fibers. A downstream vent is possible, and is required for natural fibers due to their propensity to pick up moisture.

Multiple extruder apparatus for compounding thermoplastic resin and reinforcing fibers incorporates a resin extruder in which thermoplastic resin are melted and a compounding extruder in which the molten thermoplastic resin is mixed in intimate contact with long reinforcing fibers of at least one inch in length. The melted thermoplastic resin is introduced into the compounding extruder at a point downstream of the inlet point for the reinforcing fibers, so that the fibers are mechanically worked and heated before coming into contact with heated, molten thermoplastic resin.

The extrude from the compounding extruder consists of a homogeneous, molten mass of thermoplastic resin having discrete lengths of fibers randomly dispersed therein.

What is claimed is:

1. Apparatus for compounding reinforcing fibers with a thermoplastic resin comprising a source of supply of thermoplastic resin and resin extruder having an inlet for receiving thermoplastic resin from said source of supply, an outlet, an elongated, rotatable extruding screw extending between said inlet and said outlet handling means for conveying thermoplastic resin from said source of supply thereof into said resin extruder inlet, whereby thermoplastic resin are mechanically pumped by said resin extruder screw from said inlet to said outlet and are thereby heated and melted a compounding extruder comprising a single, continuous, straight barrel and an elongated, rotatable, power screw extending continuously therein between an inlet end and a discharge end of said barrel, said barrel having first and second inlet ports on said inlet end communicating with said power screw, said second inlet port being continuously connected in fluid flow relation to said outlet of said resin extruder for receiving molten thermoplastic resin therefrom at a location along said elongated power screw downstream from said first inlet port, and between said first inlet port and said discharge end of said compounding extruder barrel, and said power screw having substantially continuous thread means of generally helical configuration a converging, flow restricting passage at said discharge end of said barrel of substantially less diameter than the diameter of said barrel a source of supply of discrete, predetermined lengths of reinforcing fibers connected to said first inlet port of said compounding extruder, and means for feeding said fibers into said first inlet port, whereby the fibers are heated and mechanically worked by said power screw of said compounding extruder before coming into mixing contact with molten, thermoplastic resin, and the fibers are continuously confined under pressure within said screw barrel by said thread means and advanced by said thread means of said power screw as a continuous mat past said second inlet port for thorough initial wetting by molten thermoplastic resin, and said fibers and said thermoplastic resin intermix in said power screw to form a homogeneous molten mass of thermoplastic resin having discrete, discontinuous lengths of reinforcing fibers randomly and homogeneously dispersed therein.

2. Apparatus as defined in claim 1 wherein:
Said thermoplastic resin handling means comprises weighing and conveying apparatus positioned to receive thermoplastic resin from said source of supply thereof and to feed thermoplastic resin into said resin extruder inlet at a predetermined weight rate and said means for feeding said fibers into said first inlet port of said compounding extruder comprises weighing apparatus on which fibers are received and weighed and conveying apparatus positioned adjacent to said weighing apparatus to feed discrete lengths of reinforcing fibers into said first inlet port of said compounding extruder at a predetermined weight rate.

3. Apparatus as defined in claim 2, wherein:
Said weighing apparatus for said thermoplastic resin and said weighing apparatus for said reinforcing fibers each comprises a loss-in-weight feed scale.

4. Apparatus as defined in claim 2 wherein:
Said source of supply of reinforcing fibers comprises continuous lengths of fibers on supply means positioned on a feed scale to serve as a fiber source, and said means for feeding said fibers comprises a pair of feed rollers rotating at a predetermined speed and positioned adjacent to said supply means, and a movable cut-off knife, and a feeder hopper positioned in fiber-receiving relation to said feed rollers and having an outlet connected to said first inlet port of said compounding extruder, whereby said feed rollers pull continuous lengths of fibers from said supply means and said cut-off knife cuts the fibers to said predetermined lengths, with the cut fibers being received in said feeder hopper, from which they are conveyed into said first inlet port of said compounding extruder.

5. Apparatus as defined in claim 2 wherein:
Said pellet-handling means further comprises a dryer through which thermoplastic resin are conveyed for drying prior to being introduced into said inlet of said resin extruder.

6. Apparatus as defined in claim 2 wherein:
Said weighing and conveying apparatus for said thermoplastic resin comprises a conveyor supported on a feed scale for conveying thermoplastic resin to said inlet of said resin extruder at a predetermined weight rate.

7. Apparatus as defined in claim 1 wherein:
A preforming device for forming the extrudate from said compounding extruder into a predetermined size, weight and shape of preformed mass is directly positioned at said discharge end of said compounding extruder.

8. Apparatus as defined in claim 8 wherein:
Said preforming device comprises a pair of rollers having an input side and an output side and defining a nip, said input side being a fluid-flow communication with said discharge end of said compounding extruder to receive extrudate therefrom, whereby the extrudate is formed as a sheet-shaped preform by passing through said nip between said rollers, and further including a cut-off means adjacent the output side of said pair of rollers to cut sheet preforms into desired lengths.

9. Apparatus as defined in claim 1 wherein:
Said screw of said resin extruder and said power screw of said compounding extruder are of different sizes and have different volume flow capacities.

10. Apparatus as defined in claim 1 wherein:
separate, power-drive means are independently, drivingly connected to said screw of said resin extruder and to said power screw of said compounding extruder for driving said screw and said power screw at predetermined rotational speeds, whereby said screw of said resin extruder and said

power screw of said compounding extruder can be independently driven and controlled.

11. Apparatus as defined in claim 1 wherein:
Said second inlet port is at a location on said barrel such that at least one-half the overall length of said power screw extends between said second inlet port and said discharge end of said barrel.

12. Apparatus as defined in claim 8 wherein:
said preforming device comprises means for forming said extrudate from said compounding extruder into an elongated billet, said preforming device having a discharge end through which a measured volume of an elongated billet comprising a homogeneous mixture of thermoplastic resin and reinforcing fibers is discharged the apparatus further comprising a cut-off knife positioned for movement across said discharge end of said preforming device to cut said elongated billers to predetermined lengths suitable for reception in a compression molding machine and a compression molding machine positioned adjacent to said preforming device and shuttle plate means positioned immediately adjacent to said discharge end of said preforming device and reversibly movable between said preforming device and said compression molding machine to receive said elongated billets one at a time from said discharge end of said preforming device and deliver them to said compression molding machine.

CHEMICAL TREATMENT ON INTERFACIAL ADHESION

Alkali treatment of cellulosic fibers, also called mercerization, is the usual method to produce high quality fibers. Alkali treatment improves the fiber-matrix adhesion due to the removal of natural and artificial impurities. Moreover, alkali treatment leads to fibrillation which causes the breaking down of the composite fiber bundle into smaller fibers. In other words, alkali treatment reduces fiber diameter and thereby increases the aspect ratio. Therefore, the development of a rough surface topography and enhancement in aspect ratio offer better fiber-matrix interface adhesion and an increase in mechanical properties. Alkali treatment increases surface roughness resulting in better mechanical interlocking and the amount of cellulose exposed on the fiber surface. This increases the number of possible reaction sites and allows better fiber wetting. The possible reaction of the fiber and NaOH is as below.

Image 4: Preparation of NaOH solution

Fiber-OH + NaOH ------- Fiber-$O^-Na^+H_2O$

Alkali treated natural fibers favoured the reinforcement in the epoxy matrix in the composite showing perfect chemical bond and better interface adhesion and thus increased the tensile strength of Hybrid composite samples. The failure of Natural fiber–epoxy Hybrid samples, characterized by brittle failure, showed long tails after the predominant damage. It is thus estimated that an interfacial interaction in the present composite would result in a higher elongation to break due to alkali treatment. We can clearly absorb the fiber wetting of the treated fiber and also good fiber-matrix,interaction.

Imag 5: Soaking of fiber in NaOH solution

The weight loss was calculated from the following equation:

$$\text{Weight loss} = W_0 - W_1/W_0 \times 100\%$$

Where w_0 denotes the weight of sisal fibers before NaOH treatment, and w_1 the weight of fibers after having been treated with NaOH.

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For example:
$W_0 = 500g$
$W_1 = 424g$
Weight loss= 500-424/500×100
Weight loss =15.2%

Image 6: Cleaning with Distilled water Silane Treatment

Silane is used as coupling agents to modify fibre surface. It undergoes several stages of hydrolysis, condensation and bond formation during the treatment process with the fibre. Silanols forms in the presence of moisture and hydrolysable alkoxy groups. It reacts with cellulose hydroxyl group of the fibre and improves fibre matrix adhesion to stabilize composite properties (Xue et al., 2007). The chemical composition of silane coupling agents (bifunctional siloxane molecules) allows forming a chemical link between the surface of the cellulose fibre and the resin through a siloxane bridge. This co-reactivity provides molecular continuity across the interface region of the composite. It also provides the hydrocarbon chain that restrains fibre swelling into the matrix (Wang et al., 2007; George, Sreekala, & Thomas, 2001).

Image 7: Drying in room temperature

Image 8: Drying in oven

Natural fibres exhibit micropores on their surfaces and silane coupling agent act as a surface coating which penetrates into the pores and develop mechanically interlocked coating on their surface. Silane treated fibre reinforced composite provides better tensile strength properties than the alkaline treated fibre composites (Valadez-Gonzalez, Cervantes-Uc, Olayo, & Herrera-Franco, 1999). Seki (2009) investigated the effect of alkali (5% NaOH for 2hrs) and silane (1% oligomeric siloxane with 96% alcohol solution for 1 hr) treatment on the flexural properties of jute epoxy and jute polyester composites. For jute epoxy composites alkali over silane treatment resulted in about 12% and 7% higher strength and modulus properties compared to the alkali treatment alone. Similar treatment led to around 20% and 8% improvement for jute polyester composites. Sever, Sarikanat, Seki, Erkan, and Erdog (2010) applied different concentration of (0.1%, 0.3% and 0.5%) silane(γ-Methacryloxypropyltrimethoxysilane) treatment on jute fabrics polyester composites. Tensile, flexural and interlaminar shear strength properties were investigated and compared with untreated composites. The results for 0.3% silane treated composites showed around 40%, 30% and 55% improvement in tensile, flexural and interlaminar shear strength respectively

Image 9: weighing of fiber

UPSTREAM SYSTEM CONSIDERATION

Feeders are a critical component in any twin-screw extrusion system. The primary functions are maintaining formulation consistency, keeping a constant throughput, introducing ingredients in the proper order, and regulating mass transfer properties of the process. Various delivery mechanisms are used, including vibratory, single screws, and twin screws. Liquid feed streams use either piston or gear pumps to set the rate to the extruder, depending upon the viscosity, and can be heated or ambient. Gravimetric controls modulate the feed mechanism to maintain a constant mass flow to the extruder, using an algorithm based on materials usage as measured by a load cell.

Image 10: Twin screw extruder

Image 11: Twin screw

Controlling fiber delivery to the twin-screw extruder can be complex . For brevity and simplicity, this discussion addresses an example for glass, carbon, and natural fibers, which are roved as one or several ropes, and are of finite length wound to some length on tubes. While it is possible to gravimetrically control fiber payoff from rolls, in practice recipe control can assume a given weight per length for the roving, which may be verified and adjusted from time to time by analyzing the final product. The number of rovings used tends to cancel out weight per length variations in individual rovings. The weight rate to the extruder, therefore, is really a length rate, which is expressed as:

$$W_C = n \times w_R \times V_R$$

W_C is the calculated weight rate in lbs.per min

n is the number of rovings being fed

W_R is the weight per foot of each roving

V_R is the velocity of each roving in feet per min

V_R, the roving is important because the velocity has boundaries set by the lineal intake rate of the extruder screws. The critical lineal intake rate, V_C is a function of the intake screw element geometry and the screw speed. The critical velocity is given by:

$$V_C = N_{rpm} \times V_1$$

N_{rpm} is the screw speed of the extruder in rotations per min

V_1 is the length of roving the screws will “pull in” in one turn

Depending upon the fiber and the design of the extruder intake system, V_C will fall into some range, which for discussion might be:

$$115\%\ V_C > V_R > 90\%\ V_C$$

The above reflects that the extruder screws can take a little more fiber without feed instability, or a little less before excessive fiber breakage or roll tension occurs. This range allows fairly straight forward control of the rate by the adjustment of V_R the roving speed and the roving count as needed.

The hardware involved includes:

A payoff for active roving packages and those in reserve.

- A payout roll set with fiber sensor.
- A two-roll puller to place the rovings into the appropriate barrel feed port.
- A control system to coordinate the roll speeds.

To understand the basic operation, consider, for example, that the system is producing at steady state running at a certain roving count and velocity, but a roving package runs out. That causes the velocity, V_R, to increase while another roving is patched in. As soon as the new replacement is fed, V_R the velocity resumes its speed to continue achieving the target total rate.

CONCLUSION

If a higher fiber throughput rate is required, an increase in roving count is also possible. Rovings are fed into the process either semi-automatically or manually, depending on the process. Natural fibers have the ability to reinforce plastics due to their low cost, high specific strength and biodegradability, but their use has been limited by temperature sensitivity, degradation by moisture, variation in quality, poor surface adhesion to hydrophobic polymers and separation from polymer during extrusion molding. All of these disadvantages contribute to the poor performance of the composite. Numerous researches have dealt with the effect of retting, physical modifications and chemical pretreatments on composite properties to address the first four disadvantages, but a very few have dealt with the process of extrusion compounding which addresses the last two disadvantages. The goal of this study, therefore, was to focus on extrusion compounding and its parameters (barrel zone temperature and screw speed) as a solution to these problems and to ensure that the natural fibers were uniformly dispersed within the melt, thus yielding extrudates and composites with better properties. The low viscosity polypropylene matrix is better to achieve good wetting properties, which plays an important role in the interfacial bonding between the fiber-matrix which assists to attain higher shear stress in the composite specimen. The long fiber composite materials can be used in semi structural applications, automobiles, aerospace and marine applications.

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