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# Injection Molding Parameters Influence on PE Composites Parts

Koffi A.[a], *Koffi D.[a], Toubal L.[a]
*Laboratory of Mechanics and Eco-Materials (LMEM), Department of Mechanical Engineering,*
*University of Quebec at Trois-Rivières (UQTR), CP 500, Trois-Rivières (QC) , G9A 5H7, Canada*

**Abstract:** Thermoplastic matrix polymer composites have gained commercial success in the semi structural and structural applications. Polyethylene (PE) is one of the most versatile and widely used thermoplastics in the world because of its excellent properties like toughness, near-zero moisture absorption, excellent chemical inertness, low coefficient of friction, ease of processing and unusual electrical properties [1,2]. Among the Processing techniques of Polyethylene matrix polymer composites, Injection molding (IM) is one of the common used. It often happens that only fiber content is the most variable parameter during the IM Process. This review reports how the other processing parameters such as melt temperature, mold temperature, injection speed ,holding pressure, injection pressure and to some extent fiber content had influenced mechanical, morphological, tribological properties of polyethylene composites as well as water absorption, bond strength and electrical conductivity.

**Keywords:** Review, Polyethylene, Composite, Injection molding parameters.

## I. INTRODUCTION

Polyethylene (PE) is one of the most widely used thermoplastic in the world because of its good properties that can be used such as toughness, near-zero moisture absorption, excellent chemical inertness, low coefficient of friction, ease of processing .PE is used in many applications such as pipes, sheets, containers and other products and is also used as an electrical insulating material for wire and cable applications because of its high dielectric strength and very low electrical conductivity[1, 2].The mechanical and physical properties of PE depend significantly on variables such as the extent and type of branching, the crystal structure and the molecular weight. New composites that include PE as the matrix is widely used in many applications with better mechanical and physical properties compared to the polymer alone. PE composites are used in packaging, electrical, thermal energy storage, automotive applications, biomedical and space applications [1-10].

Polymer-natural fiber composites are a relatively new group of environmentally friendly materials. After decades of high-tech development of artificial/synthetic fiber such as carbon, aramid, and glass, it is remarkable that natural fiber such as kenaf flax, jute, hemp, and sisal have attracted renewed interest, especially as a glass fiber substitute in the automotive industry [11-17]. The various advantages of natural fibers over man-made glass and carbon fibers are low cost, low density, comparable specific tensile properties, non-abrasive to the equipments and non-irritation to the skin, reduced energy consumption, less health risk, renewability, recyclability and bio-degradability.

The major problem, however of natural fibers/polymers composites is the incompatibility between the hydrophilic natural fibers and the hydrophobic thermoplastic matrices. This leads to undesirable properties of the composites. It is therefore necessary to modify the fiber surface by employing chemical modifications to improve the adhesion between fiber and matrix .There are many factors that can influence the performance of natural fiber reinforced composites. Apart from the hydrophilic nature of fiber, the properties of the natural fiber reinforced composites can also be influenced by fiber content/amount of filler. In general, high fiber content is required to achieve high performance of the composites [18-23].

Polyethylene composites are processed by many techniques such as extrusion, injection molding, compression molding, and rotational molding [1]. Mechanical properties for example of fiber filled polymer based composites depend on several factors such as fiber content and orientation, fiber length ,fiber-matrix interfacial computability, processing technique and processing parameters[24-30].

Temperature has a profound influence of the formation of any materials. Any change in the microstructure has a direct impact on materials properties, such as tensile strength and modulus. However, only a limited number of studies were conducted in the past to investigate the influence of processing temperature on the Mechanical properties of various types of natural fiber reinforcing composites [31-34]. Some research have already shown the influence of temperature on the elastic modulus of polyethylene composites reinforced with Keratin Fibers[33]. Although the tensile properties of kenaf fibers bundle were not significantly affected as long as the processing is less than 1.

Increasing the pressure during processing of polypropylene hydroxyapathite composites using hot press has shown to increase the composites density, crystallinity, tensile strength and modulus [35]. The same study also indicated the influence of temperature on the composites' impact resistance, tensile strength and modulus. Increasing screw speed was also shown to improve fiber distribution in the matrix but at the same time reduced the fiber aspect ratio leading to poorer mechanical performance of the composites [36].

A better understanding on how processing may affect mechanical properties of composites would lead to better quality control of the resultant composites materials particularly where optimum mechanical performance is expected. Therefore, suitable processing techniques and parameters must be carefully selected in order to yield the optimum composite products [30].

Injection molding (IM) is one of the common used processing techniques because of economy, vast quantity and no post-molding finishing operation. IM is characterized by rapid production rates and is principally a mass-production processing techniques. It is for example used to produce at least 50% by weight of short fiber reinforced polymers. It has been showed that injection molding operational conditions and the amount of fiber could affect the properties of composite materials [37, 38]. However, studies on how injection molding parameters influencing the properties of composites are very limited [39].

The aim this review is to report and show , how the other processing parameter such as melt temperature, mold temperature, injection speed ,holding pressure, injection pressure and to some extent fiber content have influenced mechanical, morphological, tribological properties of polyethylene composites as well as water absorption, bond strength and electrical conductivity.

It will be initially mentioned the injection parameters and their setting in its generality and then reported their effect on polyethylene composites.

## II. INJECTION PARAMETERS AND GENERAL SETTING [40]

In injection molding process, the compounded samples are preheated in cylindrical chamber to a temperature at which it can flow and then it is forced into a cold closed mold cavity by means of quite high pressure, which is applied hydraulically through the ram or screw type plunger. The screw rotates to pick up the PE composite and melt it, mix the melt and deliver it to the closed mold. The screw is then moved forward to force a fixed volume of the molten polymer into the closed mold. After melting, PE composite is solidified in the cool mold, the screw rotates and moves backward to charge the polymer composite for the next cycle.

There are over 200 different parameters that must be established and controlled to achieve proper injection molding of a plastic part. These parameters fall within four major areas: pressure, temperature, time, and distance [40]**.**

### A. PRESSURE (BACKPRESSURE, INJECTION PRESSURE, HOLDING PRESSURE, CLAMP PRESSURE*)*

The first pressure to consider is backpressure. This is pressure that is created during the return action of the screw after injecting material. This pressure is used for better mixing of the plastic, removing small amounts of trapped air, and controlling the weight of the shot by maintaining an accurate density of a given volume of melt. The maximum setting is needed because anything over that will cause too much shearing of the plastic and result in thermally degraded plastic.

The next type of pressure to consider is injection pressure. This is the primary pressure for injecting 95% of the molten plastic into the closed mold. Normally, the highest pressure and fastest fill rate are the best condition. However, high pressure will increase molded-in stress. And, that stress will be released at some time. So, it is better to determine the minimum amount of pressure necessary to fill the mold, and then use all of it.

Once the majority of the plastic (95%) has been injected using standard injection pressure, the machine should drop into hold pressure. This pressure is about half of the injection pressure and is used to finish filling the mold by packing the molecules together in an orderly fashion. Hold pressure is required until the gate freezes off, normally in 3 to 4 seconds. Once that happens, hold pressure has no more effect on the molecules on the other side of the gate.

The only reason to have clamp pressure is to keep the mold closed against injection pressure. Therefore, the amount of clamp pressure required is based on the material being molded. The easier flow materials require less injection pressure, thus they require less clamp pressure [40]**.**

### B. Heat[40,41]

The next parameter area is heat. Heat is used to soften the plastic to the point of being able to inject it, but heat is also found in the mold and in the heat exchanger of the machine.

Melt temperature is one of the most important factors in molding plastic parts. It is the key to successful molding. If it is too low, the resin might not be completely melted or it might be too sticky to flow. If the melt temperature is too high, the resin could degrade. Melt temperature is in turn influenced by Barrel temperature setting, Screw speed, Screw back pressure, and Residence time. Most melting of the resin occurs because of the frictional heating from the screw rotation inside the barrel. The barrel heater bands serve mainly to keep the resin at the appropriate temperature.

The most common method used for cooling the plastic once it is injected into the mold is a set of water lines. These lines are connected to a source of temperature-controlled water that circulates through the mold and pulls out heat that is building up in the mold over time. Actually, the water is being used to maintain the temperature of the mold and should be the same temperature leaving as entering [40, 41].

Suggested melt and mold temperatures for specific materials are shown in the Table **I**

**Table I: Melt and mold temperatures for specific materials [42].**

| **Material** | **Abbreviation** | **Melt Temp °c** | **Mould Temp °c** |
|---|---|---|---|
| Acrylonitrile Butadiene | Styrene ABS | 240-280 | 50-80 |
| Styrene Acrylonitrile | SAN | 200-270 | 40-80 |
| Acrylate Styrene Acrylonitrile | ASA | 240-280 | 40-80 |
| ASA/PC Blend | ASA + PC | 260-300 | 60-90 |
| Poly Methyl Methacrylate | PMMA | 200-260 | 50-80 |
| Low Density Polyethylene | LDPE | 170-240 | 10-40 |
| Polypropylene | PP | 200-270 | 10-40 |
| High Density Polyethylene | HDPE | 180-270 | 10-40 |
| Polystyrene | PS | 180-260 | 10-40 |
| Nylon 6.6 | PA 66 | 280-300 | 40-60 |
|  | PA 66 + Glassed Fibre | 285-310 | 80-120 |
| Nylon 6 | PA 6 | 230-290 | 40-60 |
|  | PA 6 + Glassed Fibre | 260-290 | 80-120 |
| Polyacetal | POM copolymer | 180-230 | 60-120 |
| Polybutylene Terephthalate | PBTP | 245-270 | 60-80 |
| Polyether Sulphone | PES | 320-360 | 140-160 |
| Polysulphone | PSU | 310-360 | 120-160 |
| Polycarbonate | PC | 280-310 | 80-120 |
| Polyvinyl Chloride (rigid) | PVC | 170-210 | 20-50 |

### C. SCREW ROTATION AND INJECTION SPEED

The screw rotation speed (RPM) is the rate at which the plasticizing screw rotates. The faster the screw rotates, the faster the material is compressed by the screw flights, increasing the amount of shear heating.

The injection speed (or ram speed) is the forward speed of the screw during its injection operation. For most engineering resins, the ram speed should be set to the fastest setting. However, slower injection speed at the beginning of injection may be necessary to avoid turbulent flow and Jetting, as material passes through the restrictive areas such as the gates. The injection speed should be reduced again toward the end of injection to avoid flashing at the end of stroke, and to enhance the formation of homogenous weld lines after a divided flow [41].

## III. EFFECT OF PROCESSING PARAMETERS ON PE COMPOSITE PROPERTIES

### A-Effect of Processing Parameters on Mechanical Properties

Mechanical properties of fiber filled polyethylene based composites depend on processing parameters.

C. Fetecau and al. investigated the effect of injection molding parameters on low density polyethylene reinforced with 2.5 wt% multi-walled carbon nanotubes (LDPE-MWNT) and the neat LDPE [43]. The Taguchi methodology with four factors and two levels was used for the design of the experiment [44, 45] . Melt temperature , mold temperature , holding pressure and injection speed were selected .The holding time was set to 5 s, while the cooling time to 30 s. For neat LDPE, the melt temperature is the most significant factor on the Young’s modulus. The mold temperature, injection speed and holding pressure have moderate effects. The increase of melt temperature, mold temperature and injection speed decreases the Young’s modulus, while the increase of holding pressures increases the Young’s modulus. For LDPE-MWNTs composite, the melt temperature is the most significant factor. The mold temperature has a moderate effect, but significant when compared to the holding pressure or injection speed which do not seem to assert much influence on Young’s modulus. The temperature has a decreasing effect. As mold and melt temperature increase, the Young’s modulus decreases [43].

P.S.M. Megat-Yussof and al. have investigated the effect of holding pressure and injection temperature on Oil palm empty fruit bunch + HDPE, (EFB)-HDPE. Two series of sample were prepared [30]. In one series, samples were prepared at varying holding pressure of 60, 70, 80, and 90 bars while the injection temperature was maintained at 170°C. In another series, samples were produced at various injection temperatures namely 150, 170,190 and 210 while holding pressure was fixed at 80 bars. Holding Pressure has shown to influence the composites tensile and fracture strength although with less impact on the flexural Strength. Increasing holding pressure increases molecular orientation of the polymer chains of the matrix [46]. Increased molecular orientation results in increased level of cristallinity of the composites. The injection direction during sample fabrication also influences the orientation of fibers in the composites [47]. The observed improvement in tensile properties as the holding pressure is increased is due to anisotropy. However, if the holding Pressure is increased beyond the optimal level, the molecular chain of the composites become overly packed resulting in chain entanglements and reduce cristallinity [34, 48]. Hence, increasing the holding pressure beyond its limits during injection molding process of composite can contribute to poorer tensile properties.

Flexural strength is less affected by the holding pressure due to difference in load application compared to that in tensile mode. In flexural test, the load is applied normal to the fiber orientation and each fiber is experiencing both tensile and compressive forces. The influence of molecular chain orientation on flexural strength is observed to be less compared to the bond compatibility of the fiber and matrix [49, 50].

Mechanical properties of the (EFB) HDPE are also influenced by the injection temperature. For all the mechanical properties, tensile and flexural strength are the less negatively affected. Tensile strength for example decreases by 5% for every increment in the injection temperature. Similar trend is observed with fracture strength of the composites. Higher injection temperature has caused the fracture strength to decrease clearly.

Flexural strength is the most negatively affected (62%) by the increasing of the injection temperature. Continuous decrease in the flexural strength is noted as the temperature increases.

Processing (EFB)-HDPE composites at higher injection temperature has shown to give negative impact to the composites tensile, fracture and flexural strength. Utilizing high injection temperature has resulted in heat induced degradation of the fiber [51]. They concluded that, in order to obtain a composite with good mechanical properties, a lower injection temperature should be favored, as long as the polymer is well melted.

S. Panigrahi et al. investigated the mechanical behavior of Flax fiber and HDPE biocomposite, while fiber content, injection temperature and injection pressure were modified [39].

The Study showed that the tensile strength was significantly dependent on fiber content and injection temperature. Injection pressure had no significant influence on composite tensile strength. All three factors significantly influenced the flexural strength. This indicated that flexural properties are more easily influenced by processing conditions than tensile properties. Among the three factors, the factor with the most impact was fiber content, followed by injection temperature; the factor with the least impact was injection pressure [39].

### B -Effect of Processing Parameters on Mechanical Properties via density (morphology)

The literature reports and details how to efficiently improve mechanical properties via physical [52, 53] or chemical [53, 54, 55, 56] fiber modification or by the addition of coupling agents[53,57,58]. But all of these methods do not reduce the weight of the composites. The main idea to reduce weight is to foam the composite to improve the specific mechanical properties. Nowadays, more complex methods are used to control the final foam structure to produce structural foams; i.e. a material having a skin-core-skin sandwich structure. It is known that skin thickness and mechanical properties increase with decreasing mold temperature [59, 60]. Based on this information, a method was developed to produce asymmetric structural foams by applying a temperature gradient inside the mold while foaming a compound [61]. It appeared that asymmetric foams offer higher flexural modulus when the load is applied on the thicker skin, while higher impact strength is obtained when the impact is done on the face having a thinner skin. Even though mechanical properties of foams are dependent of morphological parameters such as cell size, cell density, or cell shape, it is reported that the main parameter is density [63].

Based on all the studies, HDPE-agave fiber composites were produced using a chemical foaming agent (azodicarbonamide) by C.Tissandier et al. [62]. The samples were injection molded with the objective to produce symmetric and asymmetric structures. To this aim, the temperatures of both parts of the mold were independently controlled as well as the fiber and foaming agent content. The results showed that increasing mold temperature increases skin thickness, as well as increasing the mold temperature difference increases the degree of asymmetry even if this effect was less important as fiber concentration increases. In addition, increasing fiber content increases the elastic moduli (tension, flexion, and torsion), but decreases the strength and the elongation at break. Moreover, increasing blowing agent content decreases density, elastic moduli (tension, flexion, and torsion), strength and elongation at break. Mold temperature, in the range of parameters studied, was found to have a relatively small effect on elongation at break because the lowest temperature, which was kept constant is the one mainly controlling the final morphology of the foamed composites. They finally concluded that the microcellular foams were found to have a different tensile behavior than their natural fiber-reinforced counterparts [62].

In the study done by C.Tissandier et al in years 2014 and 2015, morphological and mechanical properties as a function of temperature gradient inside the mold (0–60°C), as well as the fiber and foaming agent content using HDPE, flax fiber (FF), and azodicarbonamide (Foaming Agent, FA) have been investigated [63].

In the first part of the study, [64], the effect of processing conditions and composition on the final morphology (cell size, cell density, skins, and core thicknesses), apparent density, and density profile was reported. It was found that, cell size, cell density, skin and core thicknesses were affected by blowing agent and natural fibers contents and mould temperatures. The study also showed that, a better microcellular asymmetric structure was obtained with higher fiber and foaming agent contents and higher average mold temperature.

In the second part of the study, mechanical properties (tensile, flexion, torsion, and impact) were analyzed and were found to be strongly influenced by density reduction and natural fiber content. It was also found that fiber addition provides higher reinforcement in flexion than torsion and tension. Also, flexural modulus and impact strength were relatively unaffected by foaming agent content for the range of parameters studied [63].

B.R. Bharath Kumar et al. Studies in year 2015 are the first attempt of manufacturing syntactic foams, composites, using an industrial scale injection molding machine [65]. HDPE is used as the matrix material and fly ash cenospheres are used as the filler. The pressure and temperature used in the injection molding process are optimized to minimize fracture of cenospheres and obtain complete mixing of cenospheres with HDPE. The optimized parameters are used for manufacturing syntactic foams with 20, 40 and 60 wt. % cenospheres.

It was found that, while incomplete filling of mold cavity was obtained at low pressures for 160 and 180 °C temperatures, excessive material squeezing out of the mold is clearly seen for high pressures. High quality specimens are cast at 30–40 kg/cm2 pressures (fig. 1). High pressure can lead to greater fraction broken cenospheres, while higher temperature leads to lower viscosity of the resin resulting in runoff from the mold.
Mechanical properties were also analyzed and it is noted that with increasing cenosphere content, density and strength reduce and modulus increases

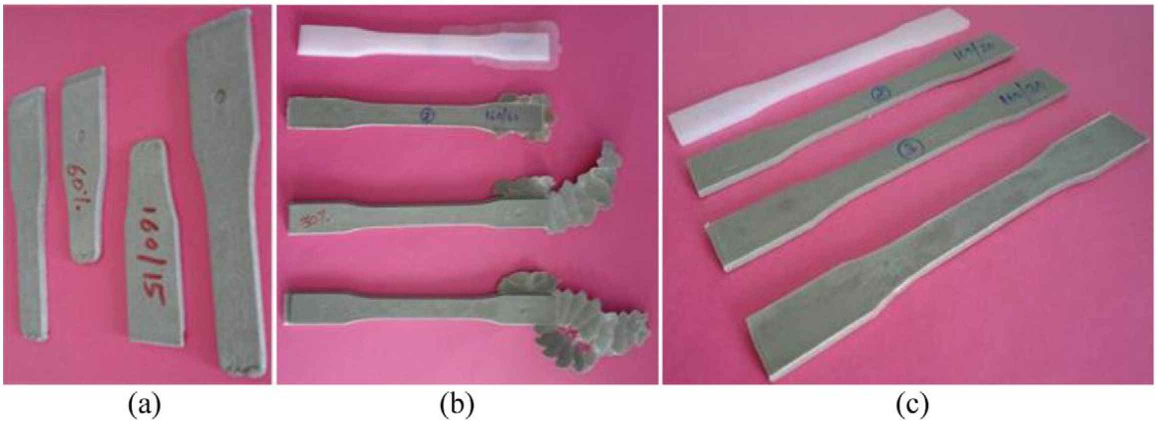

**Fig.(1).** Samples molded at pressures (a) below30 kg/cm2, (b) above 40 kg/cm2 and (c) at 30, 35 and 40 kg/cm2 [65].

**C - Effect of Processing Parameters on water absorption of PE-Composites**

Since water inside the composite may affect its physical and mechanical properties, low water absorption is desired in the final biocomposites by adjusting operating parameters. Natural fiber are highly hydrophilic in nature, they easily absorb water. Therefore, incorporation of natural fiber into polymeric matrices will generally increase the water absorption ability of the product [66]. Since higher fiber content is desired in biocomposites to achieve good mechanical properties, decreasing water absorption by controlling injection parameters like temperature and pressure are important [39].

S. Panigrahi et al. investigated the water absorption behavior of Flax fiber polyethylene biocomposite, while fiber content, injection temperature and injection pressure were modified. Table **V** presents the injections parameters and the absorption values of flax fiber-HDPE biocomposite.

It is found that when the fiber content in biocomposite is 30% and the injection temperature is low, the average water absorption of biocomposite is 0.22%; but at the same fiber content, when injection temperature increases the average biocomposite water absorption increases to 0.54%. They have concluded that it is very important to control the injection temperature to decrease the biocomposite water absorption when the fiber content is higher.

Base on SPSS statistical analysis, they reported that fiber content and injection temperature significantly influenced the biocomposite water absorption, while injection pressure did not. When the biocomposite included less than 20% flax fiber, changing the injection temperature did not result in a big difference on the bio-composite water absorption. But when the fiber content increased to 20-30%, the biocomposite water absorption was obviously influenced by injection temperature. There was an increase of water absorption when injection temperature was higher than 195°C. This was because at higher temperature, fiber degradation occurred, thus more pores were formed between the fiber and matrix interface, which gave paths for water to enter the biocomposites [39].

### D- Effect of Processing Parameters on bond strength and Electrical conductivity of PE-Composites[43].

Carbon nanotubes have been demonstrated as the best nanofiller for improving mechanical, physical, thermal, or other functional properties of polymers due to their outstanding properties, including, among others, high elastic modulus and strength, high electrical and thermal conductivity, and high chemical resistance[67, 68].

However, the degree of conductivity of the polymers depends on the volume fraction of the filler, its geometrical aspects, and its distribution within the polymer matrix [69-74]. At low carbon nanotube concentrations, the electrical properties of the nanocomposites are similar to those of the unfilled (insulating) polymer due to the fact that the carbon nanotubes are electrically isolated from one another by the polymer matrix. When the concentration in carbon nanotubes increases up to a critical level known as the percolation threshold, resistivity decreases drastically since the carbon inter-particular distance becomes small enough to get electrons flowing through the carbon network [69-74]]. The electrical conductivity of nanocomposites also depends on the properties of the polymer host matrix. Since the polymer host matrix is an electrical insulator, and electrons move from one carbon nanotube to another, the higher the crystalline structure, the lower the volume fraction of carbon nanotubes required to obtain conductive nanocomposites [69-74]. The use of carbon nanotube-filled polymeric composites and the overmolding technology is promising solution for the fabrication of two-component parts, as their electrical properties are matched by a good mechanical strength. For two-component injection molding, the adhesion may be influenced by almost every factor involved in the molding process. However, the relevant processing parameters influencing the adhesion strength are: melt and mold temperatures, injection and hold pressures, cooling and holding times, back pressure. and injection velocity [ 75-78]. These factors have a direct influence on the morphology, molecular orientation, and entanglement within the weld line-forming process. [75,76] Particularly in case of carbon nanotube-filled composites, one of the major difficulties with injection molding is the formation of the polymer-rich, non-conductive zone and carbon nanotube-rich, conductive zones within the injection-molded parts[43].

Based on all information above, F. Stan et al evaluated in year 2013 the adhesion of LDPE to the LDPE filled with 2.5% multi-wall carbon nanotubes (LDPE/MWCNT) using the two-component injection-molding method, whereby melt and mold temperature are modified [43] . It was found that the variation of the volume resistivity of the LDPE/MWCNT composite as mold temperature for a melt temperature of 230 °C, the volume resistivity decreased. However, the mold temperature has a smaller decreasing effect on the volume resistivity. The volume resistivity of the LDPE/MWCNT composite for the mold temperature of 60 °C decreased with increasing melt temperature. The volume resistivity of the LDPE matrix is somewhat unexpected since the LDPE is one of the most electrically insulating polymers. The incorporation of 2.5 wt. % MWCNTs in the LDPE has improved the conductivity of the LDPE, but the enhancement effect of the electrical conductivity is weak. The weak effect on the electrical conductivity can be attributed to the poor dispersion of MWCNTs and/or the development of nanotube agglomerates during the injection-molding process. [73,74,77-81]. Moreover, in their study the electrical percolation threshold was not reached [43].

It was also shown that the bonding strength between the LDPE and the 2.5 wt. % LDPE/MWCT composite increases with increasing melt and mold temperatures. At higher mold temperatures, however, the bonding strength slightly decreases with increasing melt temperature. Increased bond strength was attributed to a better interaction/diffusion between the polymer chains [43].

### E Effect of processing parameters on tribological properties of PE-composites

Literature on injection molding Processing Parameters effect on tribological Properties of PE-Composites remains until today very poor. The few investigations that have been carried out related only to the ultra-high molecular weight polyethylene (UHMWPE). UHMWPE possesses excellent wear resistance, high impact strength, good sliding quality, and low friction loss, and its self-lubrication performance can be widely used in engineering applications [82-84]. Most UHMWPE specimens are processed by compression molding or extrusion molding because the viscosity of UHMWPE is very high, which means it does not flow well. Therefore, it is difficult to mold by injection molding. **I**t's only in year 2009, that Hsien-Chang Kuo et al. investigated the relationships between molecular orientation and different injection molding conditions; the effects of tribological characteristics of UHMWPE wear parameters; and also the wear mechanism on worn surfaces. The variable parameters of the injection molding process were melt temperature, mold temperature and injection velocity [85].

Their work revealed, that the UHMWPE friction coefficient as well as wear volume loss are significantly affected by different injection molding. The increase in friction coefficient that is observed under different injection molding conditions is attributed to the frozen layer. Higher friction coefficients are found at a melt temperature of 280 ◦C, mold temperature of 70 ◦C and injection velocity of 210mm/s when the sliding direction is parallel to the melt flow direction. The lowest wear volume loss is found at a melt temperature of 280 ◦C, mold temperature of 90 ◦C and injection velocity of 210 mm/s, when the sliding direction is parallel to the melt flow direction. Similarly, the variation in friction coefficient and wear volume loss with different injection molding conditions show the same trend as for the sliding direction perpendicular to the melt flow direction. For the range of different injection molding conditions of the investigation, the wear volume loss values decrease or increase as the injection molding conditions decrease or increase. The reason for this behavior is because melt temperature, mold temperature and injection velocity change the surface properties, such as the viscosity or the density of the melt, and may result in a higher temperature gradient near the mold wall because of the heat transfer effect [86]. It was also found concerning surface hardness, UHMWPE hardness decreases as the sliding contact loads increase, and the injection molding conditions have little impact on the hardness. Thus, the sliding contact load is an important factor for UHMWPE surface hardness [85].

Mohamad Raffi and co. has also discussed the wear behavior of cross-linked UHMWPE. The UHMWPE specimens are molded through injection molding techniques by varying the parameters of melting temperature (MT) [87]. Two different types of materials were used in the study, one with unirradiated UHMWPE and another with γUHMWPE. The study revealed that melting temperature has influenced the hardness and wear properties such as coefficient of friction and wear rate, respectively. The micro hardness corresponding to MT of 280°C was higher than those of 260°C and 300°C because proper bonding is achieved in MT of 280°C UHMWPE specimens. The coefficient of friction COF and wear rate of UHMWPE and γ-UHMWPE are minimum for specimens corresponding to MT of 280°C, whereas the specimens obtained at MTs of 260°C and 300°C have more COF and wear rate. The examination of the worn out surfaces with scanning electron microscope, revealed that Ironing is the predominant mechanism for the specimens corresponding to MT of 280°C, whereas ploughing and scratching mechanisms are predominant for the specimens obtained at MT of 300°C. The specimens corresponding to MT of 260°C were dominated by plastic deformation and fatigue wear

## IV. SUMMARY AND CONCLUSIONS

Tables III, IV and V summarize the effects of the main injection molding process parameters on mechanical, morphological, water absorption, bond strength and tribological properties of polyethylene composites. The plus sign in the table indicates that increasing the parameter value has an increasing effect. The minus sign refers to a decreasing effect. The number of plus or minus signs refers to the intensity of the effect. 0 means no impact

**Table III:** Effects of injection molding process parameters on mechanical properties of polyethylene composites (The plus sign indicates that increasing the parameter value has an increasing effect, while the minus sign refers to a decreasing .The number of plus or minus signs refers to the intensity of the effect. 0 means no impact)

| References | Compos-ites | Melt (inj.) Temp. | Mold Temp.. | Holding Pressure. | Injection Speed | fibre contents | | Mechanical Properties |
|---|---|---|---|---|---|---|---|---|
| [43] | LDPE-MWNT | - - - | - - | + | + | | | Young's modulus |
| [30] | HDPE-EFB | - - - | | + + +/- - | | | | fracture strength |
| | | - - | | + + | | | | flexural Strength |
| | | - - | | + + +/ - - | | | | Tensile Strength |
| [39] | HDPE-Flax Fiber | +++ | | **0** | | + + + | | tensile strength |
| | | ++ | | + | | +++ | | flexural strength |

**Table IV**: Effects of the injection molding process parameters on mechanical and morphological (The plus sign indicates that increasing the parameter value has an increasing effect, while the minus sign refers to a decreasing .The number of plus or minus signs refers to the intensity of the effect. 0 means no impact

| References | Composites | Injection Temp. | Mold Temp. | Injection Pressure. | Foaming Agent contents | fibre contents | | Mechanical and morphological Properties |
|---|---|---|---|---|---|---|---|---|
| [62] | HDPE-agave fiber | | | | -- | | | density |
| | | | | | - - | + + | | elastic moduli |
| | | | | | -- | - - | | strength |
| | | | + | | -- | - - | | Elongation at break |
| | | | + + + | | | | | Skin-thickness |
| | | | + + + | | | + | | asymmetry |
| [64] | HDPE,-flax fiber | | ++ | | ++ | ++ | | Cell size |
| | | | ++ | | ++ | ++ | | Cell density |
| | | | ++ | | ++ | ++ | | skin and core thickness |
| | | | ++ | | ++ | ++ | | asymmetry |
| [63] | HDPE- | | | | | ++ | | tensile |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Flax Fiber | | | | + | +++ | | flexion |
| | | | | | | ++ | | torsion, |
| | | | | | + | +++ | | impact |
| [65] | HDPE+fly ash ceno. | ++/- - | | ++/- - | | -- | | density |
| | | | | | | ++ | | modulus |
| | | | | | | -- | | strength |

**Table V**: Effects of the injection molding process parameters water absorption, bonding strength and tribological properties (The plus sign indicates that increasing the parameter value has an increasing effect, while the minus sign refers to a decreasing .The number of plus or minus signs refers to the intensity of the effect. 0 means no impact).

| References | Composites | Melt(inj.) Temperature | Mold Temp. | Injection pressure. | Injection Speed | Fiber contents | | Water absorption, electrical conductivity and tribological Properties |
|---|---|---|---|---|---|---|---|---|
| [39] | HDPE+ Flax Fiber | ++ | | **0** | | ++ | | Water absorption |
| [43] | LDPE/ MWCNT | | -- | | | | | volume resistivity |
| | | ++/- | ++/- | | | | | bonding strength |
| [85] | UHMWPE | ++ | ++ | | ++ | | | friction coefficient |
| | | ++/-- | ++/-- | | ++/-- | | | wear volume loss |
| [87] | UHMWPE | ++/-- | | | | | | hardness |
| | | ++/-- | | | | | | coefficient of friction |
| | | ++/-- | | | | | | wear rate |

With the Tables, it appears that studying injection molding process parameters occurs the most by PE composite with natural or bio fiber (flax, agave, Oil palm empty fruit bunch,). It is becoming increasingly clear that, using suggested mold or melt temperature for thermoplastic and particularly PE by processing wood composites for example can lead to material with poor properties. The effects of pressure or temperature on plastic and wood are different. It becomes obvious that increasing wood-fiber content may require for example increasing or decreasing injection pressure or temperature.

Some trends are also observed with the tables:

-The studied injection molding parameters, mold and injection temperature, injection and holding pressure, injection speed , fiber or foaming agent content influence positively or negatively properties of PE composites. Fiber content remains the most studied parameter in injection molding process even when the other parameters are modified.

-Mold temperature and foaming agent content are the most used parameter to improve morphological properties such like cell size, cell density, skin thickness…

- Also, it is obviously clear that mechanical properties like , strength, flexure, torsion, tensile, impact of the PE composites are strongly dependent on fiber loading

This review have shown in details how processing parameters such as melt temperature, mold temperature, injection speed ,holding pressure, injection pressure and to some extent fiber content had influenced mechanical, morphological, tribological properties of polyethylene composites as well as water absorption, bond strength and electrical conductivity. It would be very desirable to see in the coming years studies on polyethylene composites included injection parameters especially in tribology where studies about injection parameter are missing.

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