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Fabrication Process of Polymer Nano-Composite Filament for Fused Deposition Modeling

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Abstract : This report describe the development of a new Polymer nano-composite material that to be used as an altenative material for fused deposition modeling (FDM) process. This new type of Polymer nano-composites is a mixture of Polycaprolactone (PCL) as a main resin, Montmorillonite (MMT) and Hydroxyapatite (HA) as a filler. The compunding process is done using single screw extruder nanomixer machine. Then the compounded Polymer nano-composites is crushed and fed into single screw extruder which is design to produce a filament. A polymer nano-composites filament with 1.7 mm of was successfully produced by assisted of water bath and puller machine. The temperature setting for Heater 1, Heater 2, Heater 3 and Heater 4 on extruder machine are 78ºC, 114ºC, 113ºC, and 79ºC respectively. The spindle speed for extruder machine was set to 3.0 Hz, while the puller machine speed is 2.5%.

Introduction

The basic principle of FDM process offers a great potential for a range of other materials including metals, ceramics, and composites to be developed and used as long as the new material can be produced in feedstock filament form of required size, strength, and properties [1]. In order to predict the success or failure of the flow for newly developed composite materials in the FDM process, it is necessary to investigate the main flow parameters namely temperature, velocity, and pressure drop on the flow behaviour of the composite in the liquefier head [2].

From the past decades, injection moulding method are used for making bone implant for human. This implant needed custom made process since every person have a different pattern and size of bone. To produce the implant using injection moulding, actually very costly and also consumed alot of time. Means, each pattern of implant needed it's own mould. So, in order to encounter this problem, different method can be used in order to make the process more simple and faster. This is where Rapid Prototyping technique comes into action. Fused Deposition Modelling (FDM) is one of the RP techniques that can be use for this process. The advantages of using this technique is, it is based on CAD drawing before it been sent to the machine to produce the model from STL file which been converted from the CAD drawing. Therefore it is less time consuming as different pattern and size can be made just by adjusting and editing the CAD drawing [3].

For this experiment, a biocompotible polymer Polycaprolactone (PCL) is chosen. PCL is a bioresorbable polymer with potential applications for bone and cartilage repair. PCL has certain advantages relative to other polymers such as PLA (poly-lacticacid). PCL is more stable in ambient conditions, it is significantly less expensive and is readily available inlarge quantities. Much researcher currently focused on the use of PCL biocomposites and co-polymers of PCL with both natural and synthetic polymers [4-5].

Methodology of research

Materials. The biodegradable polymer used in this studies was polycaprolactone, medical grade of BGH600C in a pellets form supplied by Shenzen BrightChina Industrial Co, China.Type of MMT used in this research is Nanomer I.34TCN (modified montmorillonite) nanoclay in a powder form suppled by Nanocor Inc, America . It is specifically designed for extrusion compounding. The mineral and resin form a near-molecular blend with enhanced mechanical properties, especially in the area of heat distortion. Hydroxyapatite (HA Fluka, 3.16 kg/cm^3) was purchased from Sigma Aldrich. The specific surface area of the powder, measured by N, absorption (according to the Brunnauer-Emmet-Teller) method was found to be 33.05 m^2/g , and the particle size is 57.5 nm.

Table 1: Blend formulation of PCL with MMT and HA.

Designation	PCL (wt%)	HA(wt%)	MMT (wt%)
P8M2HA10	92	10	2
P8M3HA10	90	10	3
P8M4HA10	88	10	4

Sample preparation. The PCL which is in resin form are mix manually with MMT powder and also HA powder. These uniformly dry-mixed batches are melt-blended in a single screw extruder nanomixer (L/D = 30) with a screw speed of 20 rpm. The temperature profile of the extruder is set as 70, 78, 77 and 70 ^{o}C at the fed zone, metering zone and die, respectively. The extruded blends was cooled in water bath and subsequently, and later fed to a crusher.

Filament preparation. The Polymer nano-composites that crushed into pallet size later is fed into single screw extruder machine which have been set along with a water bath and also a roller puller machine as shown in Figure 1.

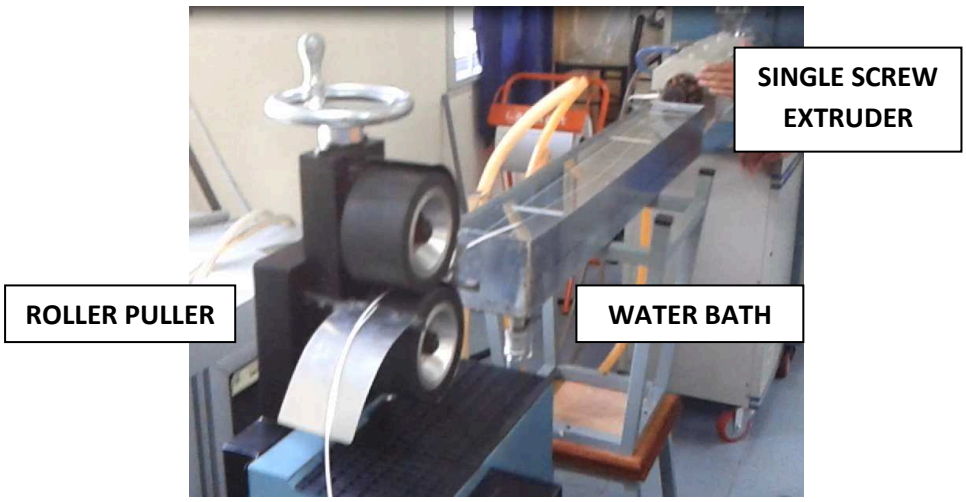

Figure 1 : Layout of the experiment conducted in producing the filament.

Result & Discussion.

The experiment was started by extruding the composites through the extruded. As it can be seen in Table 2, the result are not satisfing as the composites are hard to be driven in a long filamant as it tends to become foamy and sticks at the nozzle of the extruder. It shows that the air or room temperature are not good enough to cooled the melted composites althought the parameter of the

extruder are modifies in order to extrude the material sucessfully. It appears that these composites have a slow solidifying characteristic, as a cooling agent is needed to help the composite to solidify faster.

Next the experiment was continued by placing a water bath channel at the nozzle of the extruder. This is to help the material to cooled as it come out from the extruder as the water will act as a cooling agent in order to increase the solidfying process. As it can be seen from Table 3, the composites can be extruded out but still haven't achive the goal in producing the right size of filament. The composites tends to wrinkle and stretchen where it effects the diameter of the filament. This problem occurs as there are no constant force that drive the material out from the extruder which helps in maintaining the diameter of the filament.

Finally a roller puller were used in this experiment. As it can be seen from Table 4, the composite started to get it in shape. A better result were gain as the composite can easily being driven out from the extruder before been cooled inside the water bath in order . As the experiment is carried out there are some parameters that have to be adjust in order to produce the right dimension filament. The parameter are the the spindle speed and roller puller speed. A filament with 1.7mm± 0.05mm is succefully produce as the spindle speed were set at 2.5 Hz meanwhile the roller puller were set at 2.5%. The characteristic of these composite are the main isuues that need to be taken address.

This scenario shows that a better understanding on the properties of the composites is essentials such as its viscocity, melt flow characteristic and melting temperature will helps to decrease the problem in extruding the composites. Although PCL does have a low melting temperature which is suitable for FDM process but the solidying of this polymer should be seriously taken a note as it is also important in order to run this material on FDM machine.

Table 2 : Composites extruded without roller puller and water bath.

No	Spindle speed, Hz	Heater 1 (Celcius)	Heater 2 (Celcius)	Heater 3 (Celcius)	Heater 4 (Celcius)	Comment
1	2.5	70	70	70	70	No result
2	2.5	100	100	100	100	Wrinkle, out of dimension
3	5.0	90	100	100	90	Wrinkle, out of dimension
4	3.5	90	90	90	90	Wrinkle, out of dimension

Table 3 : Composites extruded with water bath but without roller puller.

No	Spindle speed, Hz	Heater 1 (Celcius)	Heater 2 (Celcius)	Heater 3 (Celcius)	Heater 4 (Celcius)	Comment
1	4.0	90	100	100	90	Over heat
2	4.0	80	90	90	80	Inconsistent diameter, too small
3	2.5	85	90	90	80	Inconsistent diameter, too large
4	3.5	85	90	90	80	Inconsistent diameter

Table 4: Extruder machine conducted with water bath and roller puller.

No	Puller speed, %	Spindle speed, Hz	Heater 1 (Celcius)	Heater 2 (Celcius)	Heater 3 (Celcius)	Heater 4 (Celcius)	Comment
1	3.5	3.5	80	110	110	80	Small diameter
2	3.0	3.5	80	110	110	80	Small diameter
3	2.0	3.5	80	110	110	80	Big diameter, curly
4	2.5	3.5	78	110	110	78	Inconsistant and curly
5	2.5	3.0	78	114	113	79	Consistant with ±0.5mm

Conclusion

It can be concluded that a filamment or wire 1.7mm ± 0.05mm in diameter are succesfully produced from this experiment. In order to get the filament the temparature at the exturder machine shoud be set at 78ºC, 114ºC, 113ºC, and 79ºC along with the roller puller speed should be set at 2.5%. The main problem with Polycaprolactone is its solidfying process which is very slow compare to other polymers. The water bath and roller puller does actually helps in producing the required size filament. But there are few things that should be given a serious attention such as the spindle speed, the melting temperature and also speed of the roller puller. All this parameters have to be carefully set in order to to achieve a positive result. A part of that, the temperature in the water bath also have to be maintain cooled because of the properties of the polymer which takes more times to solidifies.

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