PREPARATION AND CHARACTERIZATION OF POLYCARBONATE/GLASS FIBER –MICA HYBRID COMPOSITES

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APPLIED CHEMISTRY

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Approval of the Graduate School of Natural and A pplied Sciences, Atılım University.

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Prof. Dr. Ibrahim AKMAN
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I certify that thesis satisfies all the requirements as a thesis for the degree of Master of Science.

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This is to certify that we have read the thesis "Preparation and Characterization of Polycarbonate Glass Fiber-Mica Hybrid Composites" submitted by "Ibrahim Alsadig Mohammedkhair Alhaj" and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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ABSTRACT

PREPARATION AND CHARACTERIZATION OF POLYCARBONATE/GLASS FIBER-MICA HYBRID COMPOSITES

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The improvement of physical properties of polycarbonate is still great interest of scientists due to the huge application areas. In this study polycarbonate matrix was reinforced with glass fiber (GF), mica (MC) and in hybrid form. The preparation of composites was carried out using co-rotating twin screw micro-compounder at 280 ^{o}C and the test samples were prepared by laboratory scale injection-molding device.

The percent compositions of added fillers for PC/GF and PC/MC composites were 5%, 10%, 20%, and 30%. The total percentage of both filler was kept as 30% for hybrid composites (MC%/GF%) of which comspositions were 5/25, 10/20, 20/10, 25/5, respectively. The characterizations of obtained composites were examined via tensile test, impact test, melt flow index test, differential scanning calorimetry analysis and scanning electron microscopy methods. The obtained results showed that the best values of tensile strength were obtained for the lowest mica concentration and 20% glass fiber containing composites gave the optimum value. The concentration increment of the additives more than these values caused agglomerations and reduction of homogeneous

distribution of them in the PC matrix, which were revealed by scanning electron microscopy.

Keywords: Polycarbonate, glass fiber, mica, polymer composites, hybrid composites.

ÖZ

POLİKARBONAT/CAM FİBER-MİKA HİBRİD KOMPOZİTLERİN HAZIRLANMASI VE KARAKTERİZASYONU

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Tez Yöneticisi: Doç. Dr. Seha TİRKEŞ
Şubat 2017, 29 sayfa

Polikarbonatın fiziksel özelliklerinin geliştirilmesi, kullanım alanının oldukça geniş olmasından dolayı, hala araştırmacılar için ilgi çeken bir konudur. Bu çalışmada polikarbonat, cam elyaf ve mika kullanılarak ayrı ayrı ve hybrid olacak şekilde güçlendirilmiştir. Kompozitlerin hazırlanması, çift burgulu ekstrüder kullanılarak gerçekleştirildi. Test numuneleri, laboratuvar tipi enjeksiyon-kalıplama cihazı ile 280 ^{o}C'de hazırlandı.

Tek bileşenli kompozit için cam elyaf ve mika katkılandırma oranları 5%, 10%, 20%, and 30% olarak seçildi. Hibrid kompozitler için ise toplam katkı oranı 30% olacak şekilde düzenleme yapıldı. Buna göre hibrid kompozitlerdeki katkılandırma oranları, mika/cam elyaf için sırasıyla 5/25,10/20, 20/10, 25/5 değerlerinde tutuldu.

Elde edilen kompozitlerin karakterizasyonu için çekme testi, darbe testi, eriyik akış indeksi testi, diferansiyel taramalı kalorimetre analizi ve taramalı electron mikroskobu (SEM) yöntemleri kullanıldı. Sonuçlar incelendiğinde; mika için en düşük katkılama oranı olan % 5 konsantrasyonunda en iyi değerler saptanırken, cam elyaf içeren kompozitlerde ise en iyi sonuçlar optimum değer olan % 20 oranında saptanmıştır. Bu

konsantrasyonların kompozitler içerisinde artışı, SEM mikrografiklerinde de görüldüğü üzere eklentilerin topaklanmasına ve PC matrisi içerisinde homojen dağılımın azalmasına sebebiyet vermiştir.

Anahtar Kelimeler: Polikarbonat, cam fiber, mika, polimer kompozitler, hibrid kompozitler.

Dedicated To my Family

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Then I would like to express my deepest gratitude to my family to whom I owe a great deal, to my father also to mother, and also like to extend my deepest gratitude friends who have been waiting for my work achievement.

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LIST OF ABBREVIATIONS

PC	-	Polycarbonate
PMCs	-	Polymer Matrix Composites
GF	-	Glass Fibers
SGF	-	Short Glass Fiber
FOD	-	Fiber Orientation Distribution
MC	-	Mica
DSC	-	Differential Scanning Calorimeter
MFI	-	Melt Flow Index Test
SEM	-	Scanning Electron Microscopy

CHAPTER 1

INTRODUCTION

In modern age there have been a few scientific explorations that have had a greater influence on humankind compared to the ones gathered in the field of polymer science and technology. At the beginning of this century, new polymerization techniques have been discovered. These techniques helped to synthesis of new polymers and new materials reform. But, the innovations of new polymers for specific applications are restricted due to the technical and economic issues at the onset of this century. Thus, the properties and characterizations of current polymers have been improved by mixing polymers to obtain polymer blends or addition of inorganic fillers into polymer matrices to obtain polymer composites at a moderate cost.

The materials used in the fabrication of polymers have to be efficient, because the technology is becoming more and more sophisticated, as several performance characteristics are expected from these materials [1]. The properties of traditional polymers have been balanced by the ability of polymer matrix composites, such as low weight and ease of processability with the strength of reinforcements [2]. Because of shorter cycle times and larger potential recyclability of fiber reinforced thermoplastics they have become an area of increased interest compared to thermosetting polymers [3]. Additionally, thermoplastic polymers show large elongation to break which can be particularly beneficial in unidirectional fiber composites. The stiffness and strength of polymeric materials are often improved by the addition of fibers and fillers, which is in form of particulates, to them [4].

Today the most widely used reinforcing fibers are carbon, glass, and polyaramid [5]. Strength and stiffness of the final composites are increased by the presence of

reinforcing glass fibers permitting applications, which is not possible with resinous plastics [6]. The application of any new class of composite depends mostly on the characteristics of that composite. Including wear resistance and impact strength, behaviors at maximum stress and high temperature the composite can withstand, fatigue characteristics, corrosion behavior, etc. So the investigation of these characteristics is crucial for composite materials [7-9].

Mineral fillers in particulate form are also used in the enhancements of properties of pristine polymers. The structure, composition, characteristics of components, and interfacial interactions are the parameters affecting the properties of composites [10].

Mica (a plate like structure of crystalline alumina silicate) has excellent thermal, mechanical, and electrical properties. Therefore mica has been widely used as reinforcing filler in polymers [11]. Mica's commercial delamination may be defined as dry or wet depending on whether the process is carried out in dry state. The wet grinding for delamination is characterized by ability to disperse easily, smooth surface, high aspect ratios, and clean cut edges [12]. Thus mica preserves the natural sheen of mica. The mica addition into thermoplastic matrices improves the thermal, dielectric, and mechanical properties. It have been also reported by researchers that the addition of mica to a polymer system, significantly improves the tensile strength and modulus. The study of the effect of mica as a filler on polymer systems showed a significant improvement in tensile properties [13].

1.1 Polycarbonate

The features of Polycarbonate (PC) -an engineering plastic- are its high toughness, high strength, high heat deflection, and transparency [14]. The discovery of PC was in 1898 and the large production has been started by General Electric and Bayer since 1958. The synthesis procedures mainly based on interface process of carbonyl chloride (phosgene) with bisphenol A and transesterification of diphenyl carbonate with bisphenol A at elevated temperatures (Figure 1) [15].

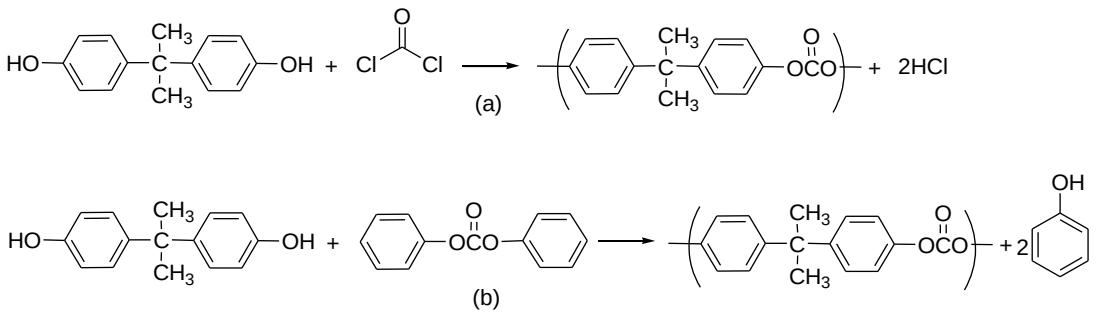

Figure 1. Synthesis route of PC: (a) interface process, and (b) transesterification reaction [15].

The ductility and high toughness of PC come from the carbonate segment in polymer chain and high heat deflection is due to the bisphenol A segment. In addition to these, PC has good electrical properties and high creep resistance [16].

In industry PC is used extensively including in a broad range of industries including glazing, electrical/electronics transportation applications (traffic light housings, sidemarker lights, etc.), household appliances, food contact applications and so on. In medical devices, the usage of PC has started before commercialization. For clinical and diagnostic appliances optical clarity is important feature due to the necessity in visibility of tissues, body fluids. In addition to these, demands of biocompatibility standards have been achieved by PC as well [17].

In summary, even though PC can be considered as a mature area of research, due to the it's possible large application areas both in academics and industry the researches are ongoing. The potential additives emerging with nanotechnology era, controlling morphology and chemical structure of the PC with new techniques will cause remaining of PC of interest for some time to come [18].

1.2 Short Glass Fiber Reinforced Polymeric Composites

We can characterize a composite as a mix of at least two parts, varying in shape or structure on a large scale with two or numerous particular stages and furthermore with

conspicuous interfaces between them [19]. The reasonable mixtures of these segments into composites offer ascent to properties that rise above those of constituents.

Polymer matrix composites (PMCs), thermoplastic or thermosetting, are one of the important subgroup of composites. The strengthening segment in a composite structure can both be irregular or nonstop, in particulate or stringy shape.

Short fibers are the most commonly employed reinforcing component for polymer matrices. The materials in fibrous form are usually much stronger than in any other form. That is actually the basic reason for the ascending of fibrous reinforcements [19].

Due to the higher strength, stiffness and ease of production, glass fibers are quiet common and widespread. The addition of glass fibers to polymers drastically causes an improvement on the stiffness, strength and the high temperature performance [20].

Glass fibers, that are non-crystalline, may consist of a range of compositions; all of these compositions have certain characteristics in common. There are four main classes of glass fibers that are commercially used [19]:

a) A-Glass: With a high alkaline grade (essentially soda-lime-silica).
b) E-Glass: Electrical grade (calcium alumina-borosilicate with low alkali oxide content).
c) S-Glass: With a high strength grade (Magnesium alumina silicate without boron oxide).
iv.) ECR-Glass: Modified E-Glass grade for chemical resistance

Fibers from any of these classes can be prepared. Although S-Glass has the higher mechanical properties such as, strength and modulus, E-glass grade fibers are the most commonly used one for reinforcing, Table 1 shows the characteristics of glass grades.

Table 1. Properties of glass fibers from different grades [19]

Material	Density g/cm^3	Tensile Strength (MPa)	Elastic Modulus (GPa)	Strain to failure (%)	Coefficient of thermal expansion (10^{-6}/K)
E-Glass	2.620	3450	81	4.9	5.0
S-Glass	2.500	3590	89	5.7	5.6
A-Glass	2.500	3050	69	5.7	8.6

Because of the few points of interest, among which are the simplicity of preparing, plausibility of acquiring complex shapes, higher strength/density proportion and reusing, short glass fiber (SGF) included thermoplastics are still great interest of scientists [21]. It is understood that a couple of properties of plastics are upgraded with joining of short glass fiber by simple inexpensive processes (extrusion and injection molding). The properties glass fiber involved thermoplastics depend on three parameters; the matrix and the properties of SGF, and also:

- Aspect ratio of fibers
- Fiber content
- Fiber orientation in matrix
- Adhesion property of fiber/matrix

1.2.1 Aspect Ratio of Fibers

The length/diameter relation (aspect ratio) is the parameter affected by the processes. During the extrusion and injection molding, the screw or ram apply shear stress which breaks the fibers and causes a fiber length distribution in asymmetric character. The number average fiber length is defined as;

$$L_n = \frac{\sum N_i L_i}{\sum N_i} \tag{1.1}$$

where N_i is the number of fibers of lengths L_i.

The replacement of mechanical load from matrix to fiber included matrix improves the mechanical properties. Fibrous filler is needed to achieve transfer of mechanical load from polymer to reinforcement. This transfer is possible if the fiber length exceeds the critical length. Tensile loads applied on fibers are zero at the ends and starts to increase gradually until a plateau in the central part of the fibers. Therefore, the load applied to the ends is less than the load on middle portion of the fibers. The fiber must have a length of at least critical length defined as the minimum length at which the center of the fiber reaches the maximum stress in the fiber to achieve effective strengthening and stiffening [22].

The fibers, which are shorter than critical length, remove out from the matrix under tensile load, therefore full load transfer does not occur. On the other hand, for the critical length case both the fiber and matrix fail along the same failure level. Increasing length more than critical length does not increase the strength of the composite, since the failure is same as that experienced at the critical length (Figure 2) [23].

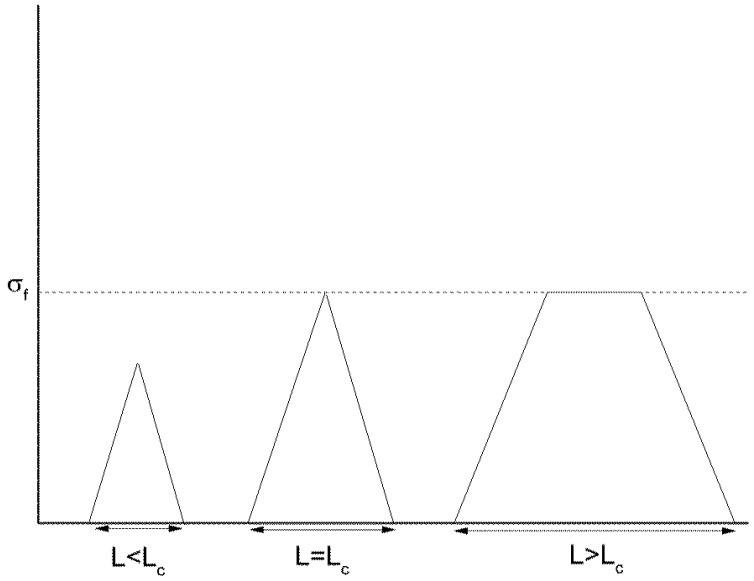

Figure 2. Simplified illustration of the variation of tensile strength in SGF reinforced polymers as a function of fiber length [23]

Because of damages on fibers during compounding and injection molding, their ultimate lengths are generally only a fraction of its initial value. The possible reasons for fracture on fibers during processing are as follows [24]:

i) Fiber/Fiber Interactions: The uncontrolled fiber breakage due to the abrasion of glass surfaces causes direct or subsequent fracture because of increased stress concentration at the fiber ends (by increasing number of fiber ends). Such failures may also happen because of bending stress caused by fiber overlap.

ii) Fiber/Machinery Interactions**:** The equipment wear, where processing fiber reinforced matrix, supports the idea of fiber/machinery interactions being important factor. This effect is due to the high shear rate on the moving surfaces.

iii) Fiber/Matrix Interactions: The fracture of fibers can occur due to the viscous forces applied by the polymer. In order to prevent this, the process temperatures should be kept as high as possible to reduce the viscosity. However, possible degradation at high temperature must be considered. In addition to this the lower screw speed can be preferred to protect the fibers.

1.2.2 Fiber Content

The glass fiber content can be expressed in terms of volume or weight fraction by following equation,

$$V_f = \frac{\frac{W_f}{\rho_f}}{\frac{W_f}{\rho_f} + \frac{W_m}{\rho_m}} \tag{1.2}$$

where W and ρ are representing weight fraction and density, respectively. The subscripts f and m denote the fibers and the matrix. The basic theoretical concept to define the dependence of glass fiber content of any physical property is based on rule of mixtures.

$$P_c = P_f V_f + P_m(1 - V_f) \tag{1.3}$$

Where P shows for any physical property such as modulus, density, etc., and V represents for volume fraction with subscripts of m and f denote the lattice and fiber, respectively. As it seen in Equation 1.3, increasing fiber content is causing increment in property of composite [25].

1.2.3 Fiber Orientation in Matrix

The fiber orientation distribution (FOD) has great importance for the mechanical properties of short glass fiber reinforced polymer matrix. During processes, such as extrusion compounding and injection molding, fiber orientations change continuously. Therefore, the isotropy is significant property for the final products. The polymer melt obtained during processing of fiber reinforced matrix experiences elongational or shear flow. The fiber orientation affected by flow processes is shown in Figure 3 for 2D deformations.

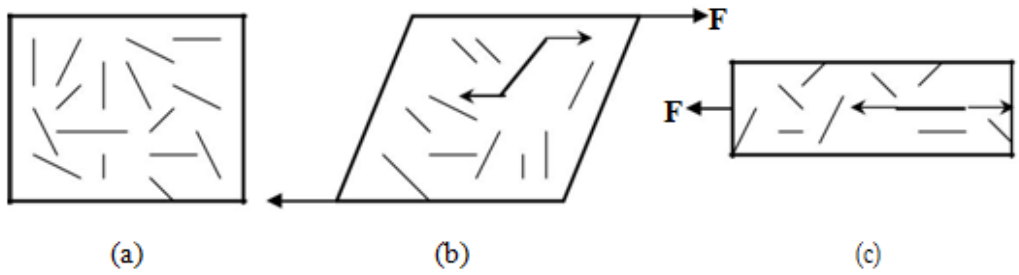

Figure 3. Representation of fiber orientation changes during flow (a) initial random distribution, (b) rotation during shear flow, (c) alignment during elongational flow [26].

The degrees of the preferred fiber orientation after the processing depend on the after processing, the degrees of desired fiber orientation depend on the flow type. The final orientation distribution, which is mainly on the way in which the mold fills, would be affected by the molten matrix viscosity [27].

1.2.4 Adhesion Property of Fiber/Matrix

The characteristics of fiber/matrix bonding strength have significant effect on the mechanical properties of obtained SGF/polymer composite. Although a strong adhesion causes the formation of the best polymer composite properties, some undesired problems may occur like decreasing in toughness, mold shrinkage increment, etc. In order to achieve efficient bonding a lot of coupling agents, which modify the surfaces of fibers, have been identified for polymers [29]. Silane coupling agents are believed to form bond between fibers and polymer matrices with proper organofunctional group. In following figure, the general formula bearing two functional groups can be seen [28].

$$R_n\text{-}Si\text{-}X_{(4-n)}$$

Figure 4. The chemical structure of silane coupling agents

1.3 Hybrid composites

The addition of various fillers into a matrix has led to the improvement of hybrid composites. The hybrid composite behavior is weighted sum of the each component in which there is a more favorable balance between their advantages and disadvantages. Also, for a hybrid composite, which includes two or more kinds of filler, the advantages of one of the fillers can complement with what are missing in the other. As a result, a balance in performance and cost can be achieved by suitable material design [29]. The shape and size of filler, content, orientation, arrangement of both fillers, and filler to matrix are the main factors determining the properties of hybrid composite.

1.4 Aim of the Study

In s work PC was used as polymer matrix and we added mica and glass fibers both separately and together to obtain single and hybrid reinforced composites, respectively. Our aim was to investigate any synergistic effect of mica and glass fibers in PC matrix. The composites were prepared via extrusion. Injection molding was used to obtain our

test samples. Because of these processing methods widely used in industrial applications, this study can be easily optimized into large scale production. The characterizations were done to elucidate mechanical, thermal, and morphological properties of the composites.

CHAPTER 2

MATERIALS AND METHODS

2.1 Materials and Processing

The materials, which were used in this work, are shown in Table 2. Before extrusion, PC, GF, and mica were dried under vacuum 80 ^{o}C for 24 hours. The percent compositions of fillers for PC/GF and PC/Mica composites were 5%, 10%, 20%, and 30%. The total percentage of GF/PC and Mica/PC were kept as 30%. The percentages of hybrid composites (MC%/GF%) were 5/25,10/20, 20/10, 25/5. The prepared dry mixtures were processed via a co-rotating twin screw micro-compounder (DSM Xplore, Netherlands) shown in Figure 5. The screw speed and process temperature were 100 rpm and 280 ^{o}C, respectively. The obtained extrudates were cut into small pieces and then dried under vacuum at 80 ^{o}C before injection moulding. For mechanical tests, the specimens were molded by using a laboratory scale injection-molding device (Figure 6) (Microinjector, Daca Instruments). The barrel and mold temperatures were 290 ^{o}C and 80 ^{o}C, respectively. The required pressure for injection was set to 5 bar.

Table 2. The materials used in the study

Materials	***Trade Name***	***Supplier***
PolyCarbonate	Lexan LS2	Sabic
Glass Fiber (4.75 mm)	PA 1	Şişecam
Mica	Mica 900	Omya Madencilik

Figure 5. The lab-scale twin screw extruder.

Figure 6. The micro-injection molding machine.

2.2 Characterization Methods

2.2.1 Tensile Test

The tensile properties were investigated by using Lloyd LR 30 K universal tensile testing machine. The load cell was 5 kN and crosshead speed was 10 cm/min (ISO 527-2-5a). The tests were conducted on dog-bone shaped specimens. The results are the average value of five tests.

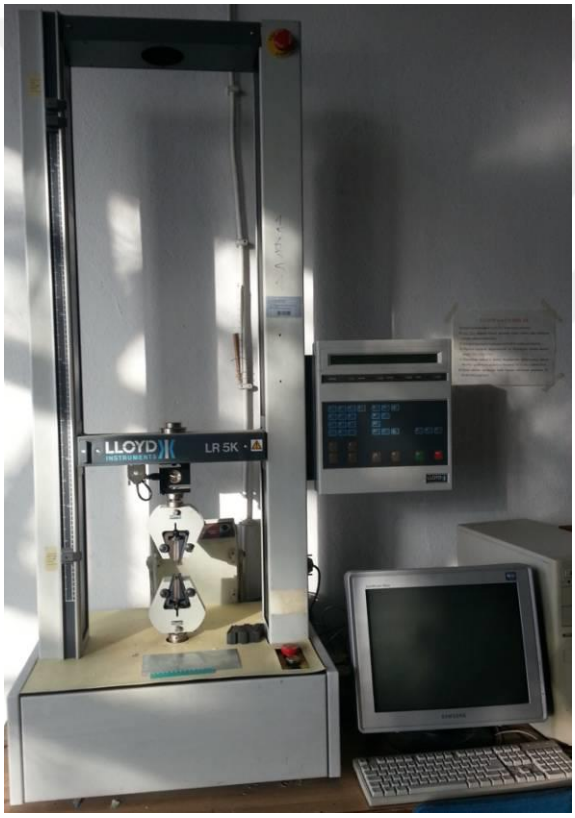

Figure 7. Tensile testing machine.

2.2.2 Impact Test

The most common impact tests, Izod and Charpy, are specified in ASTM D256-92 [30In this work, Charpy impact tests were done by Ceast Resil Impactor for PC composites in order to determine their impact strengths.

Figure 8. The impact test machine.

2.2.3 Differential Scanning Calorimetry (DSC)

Differential scanning calorimeter (DSC) measurements were studied by using a Perkin Elmer Diamond DSC at a scanning rate of 10°C/min between 50°C-300°C temperature under N_2 atmosphere.

2.2.4 Melt Flow Index Test (MFI)

MFI values were determined by using Meltfixer LT, Coesfield Material Test (Figure 9). The measurements were done under specified load of 2.16 kg at process temperature of 280 ^{o}C. The results for PC and its composites were reported through the average of ten measurements.

Figure 9. The melt flow indexer.

2.2.5 Scanning Electron Microscopy (SEM)

The GF and mica reinforced PC and PC itself were inspected by a field emission scanning electron microscope (JSM-6400 Electron Microscope). Before SEM photographs were taken, fractured sample surfaces were made conductive via coating with a thin layer of gold and the photographs were taken at x200 magnification.

CHAPTER 3

RESULTS AND DISCUSSION

3.1 Tensile Test

The aim of the tensile test is to obtain the force required to fracture a specimen and the extent to which the specimen elongates. Standard test method for tensile properties (ISO 527-2-5a) employs samples of a specified shape, typically a dog-bone.

The sample is clamped at one end and pulled at a constant rate of elongation (10 cm/min) until the center of the specimen fails.

The stress–strain curves of PC/MC, PC/MC-GF hybrid and PC/GF composites are represented in Figure 10, Figure 11, and Figure 12, respectively and the relevant tensile test data are listed in Table 3.

Table 3. Summary of the tensile properties of composites

SAMPLES	Tensile Strength (MPa)	Elongation at break (%)	Young's modulus (MPa)
PC	60.7 ± 2.2	14.4 ± 1.3	920.1 ± 13.4
PC/5% GF	62.6 ± 1.7	12.9 ± 1.4	970.3 ± 16.1
PC/10% GF	70.0 ± 2.4	11.1 ± 1.7	1090.2 ± 14.5
PC/20% GF	88.4 ± 1.8	10.9 ± 1.1	1341.6 ± 15.4
PC/30% GF	30.3 ± 2.0	4.9 ± 0.5	906.9 ± 14.9
PC/5% MC 25% GF	26.5 ± 1.7	4.5 ± 0.9	1010.4 ± 22.3
PC/10% MC 20% GF	15.7 ± 1.4	3.6 ± 0.5	784.3 ± 20.7
PC/%20 MC 10% GF	10.3 ± 1.5	9.1 ± 1.1	318.3 ± 16.5
PC/25% MC 5% GF	15.0 ± 1.8	4.2 ± 0.4	530.5 ± 14.0
PC/5% MC	88.8 ± 3.9	7.7 ± 0.8	1568.2 ± 26.3
PC/10% MC	42.7 ± 2.4	6.3 ± 0.7	964.0 ± 18.8
PC/20% MC	21.8 ± 1.5	8.2 ± 1.2	380.8 ± 13.9
PC/30% MC	17.5 ± 1.0	3.4 ± 0.3	735.8 ± 17.4

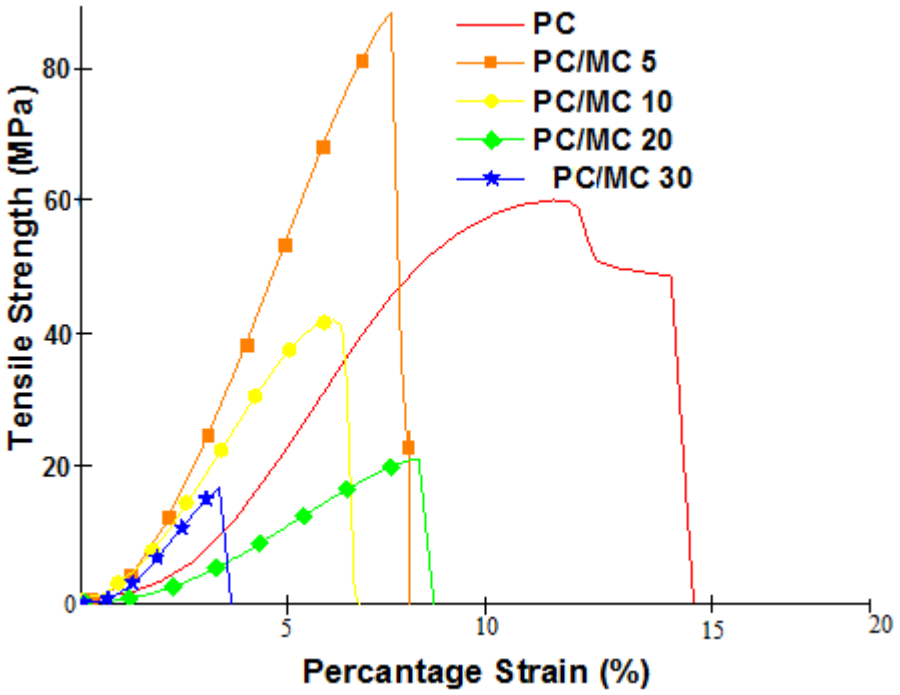

Figure 10. Stress-strain curves of PC/MC composites

According to Figure 10 and Table 3 the addition of 5% MC caused about 50% improvement in tensile strength of unfilled PC. As mica content increased, tensile

strength decreased drastically. 20% and 30% concentration of mica containing composites exhibited the lowest strength values that may be due to agglomeration of high content mica particles. In the case of elongation parameters, mica addition caused about 50% reduction relative to elongation of PC. Modulus results of PC/MC composites are similar with strength results that Young's modulus increased about 50% with the lowest mica loading with respect to PC. Further addition of mica caused decreasing in modulus of composites remarkably.

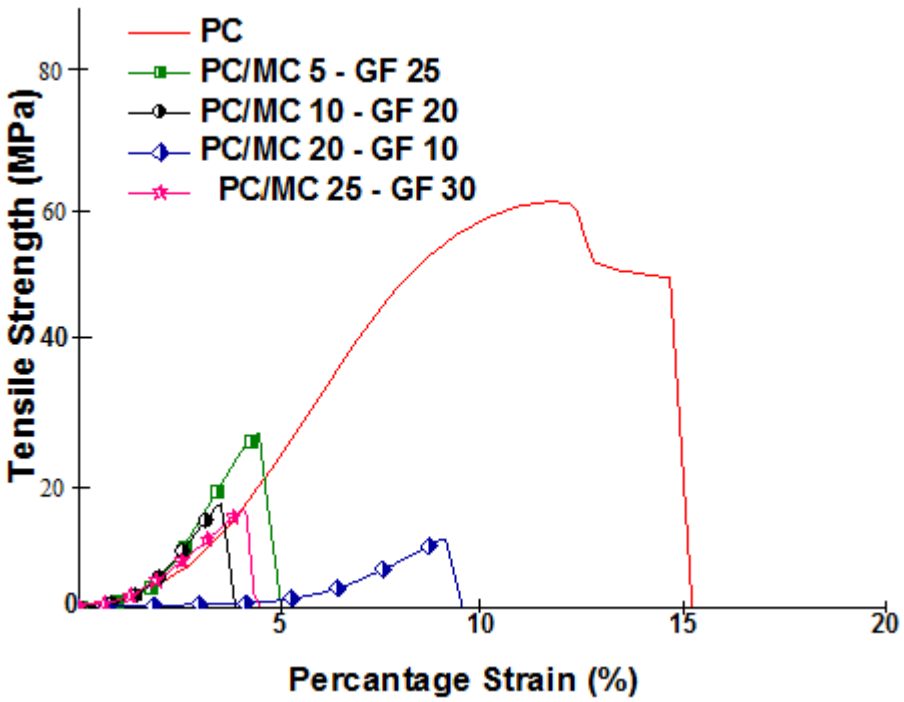

Figure 11. Stress-strain curves of PC/MC-GF hybrid composites

As seen in Figure 11 and Table 3 addition of GF and MC together resulted in sharp decreases in tensile strength. For hybrid composites, the maximum tensile strength and modulus values were obtained with minimum mica and maximum GF additions (MC 5-GF 25). Strain values of hybrid composites also dropped down as compared with unfilled PC.

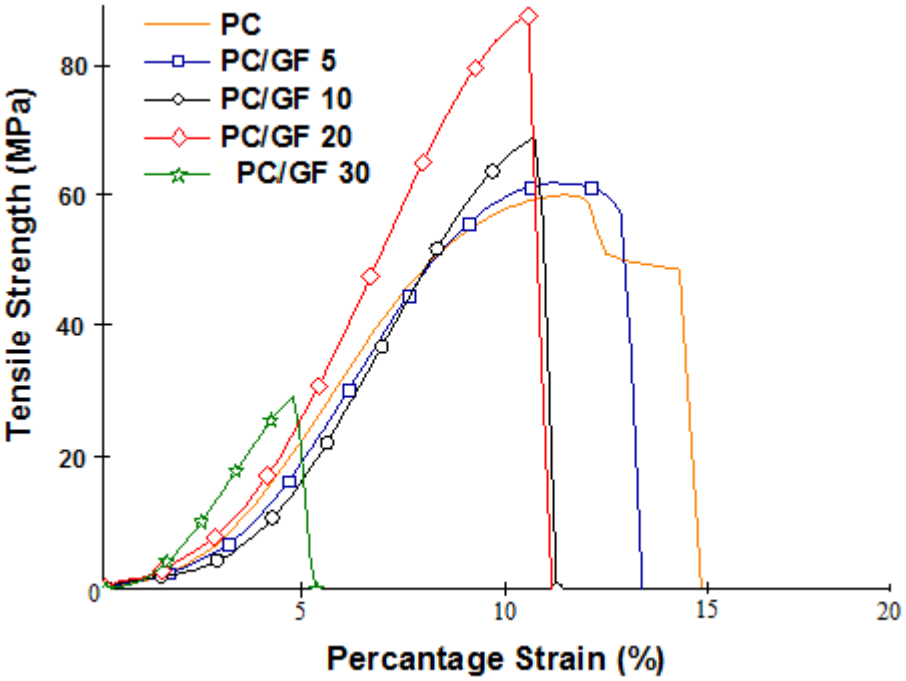

Figure 12. Stress-strain curves of PC/GF composites

According to Figure 12 and Table 3 GF addition increased tensile strength of PC up to 20% GF containing composites. 30% GF filled PC shows sharp decrease. Elongation of GF loaded composites showed decreasing trend as compared with PC. Tensile modulus of PC increased slightly with GF addition (20% GF is optimum). As a result, increment in GF concentration leads increase in tensile strength and decrease in elongation at break [31].

3.2 Impact Test

Impact test is a high strain rate test that determines the amount of energy absorbed by a material during fracture. This absorbed energy is a measure of the toughness of a material and used to study the temperature dependent ductile / brittle transition.

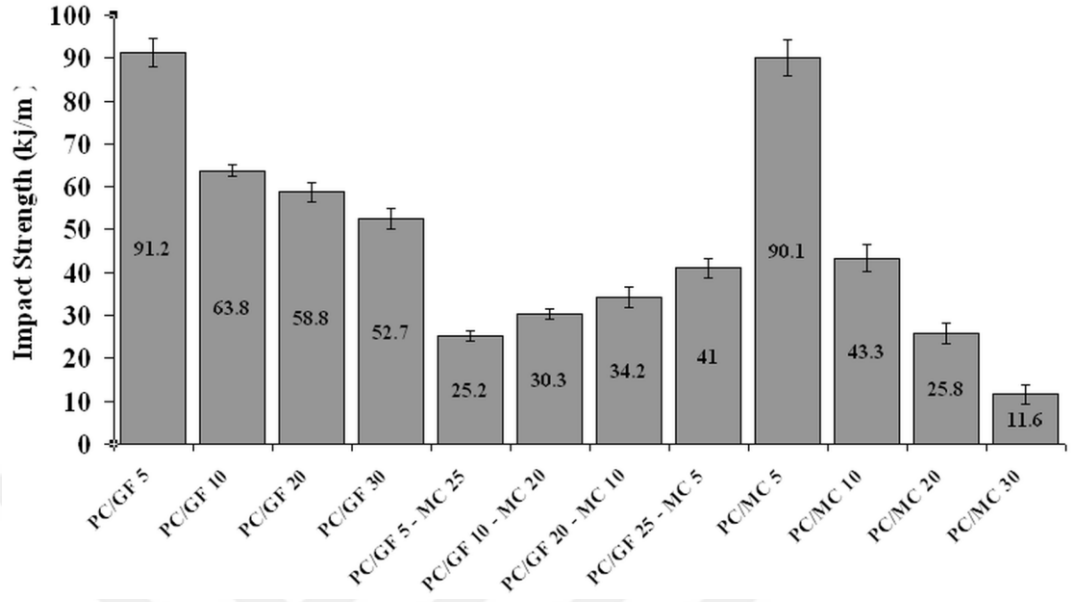

Figure 13. Impact test results of composites

Impact test results of PC and its composites are shown in Figure 13. The GF addition caused decreasing in impact strength of PC and impact strength exhibited reduction with GF content. The maximum impact strength among all composites was observed for the lowest mica content (5%MC). As mica concentration increased impact strength decreased drastically. For the hybrid composites the highest impact strength was observed for the PC/MC5-GF25 composite. As an overall result, the lowest mica loaded composites gave better results in the case of impact strength that is in accordance with tensile test results mentioned in previous section.

3.3 Melt Flow Index Test

Melt flow index is a measure of the ease of flow of the melt of a thermoplastic. It is inversely proportional to the melt viscosity of the material and defined as the mass of material in grams flowing in 10 minutes through a capillary of specific diameter and length.

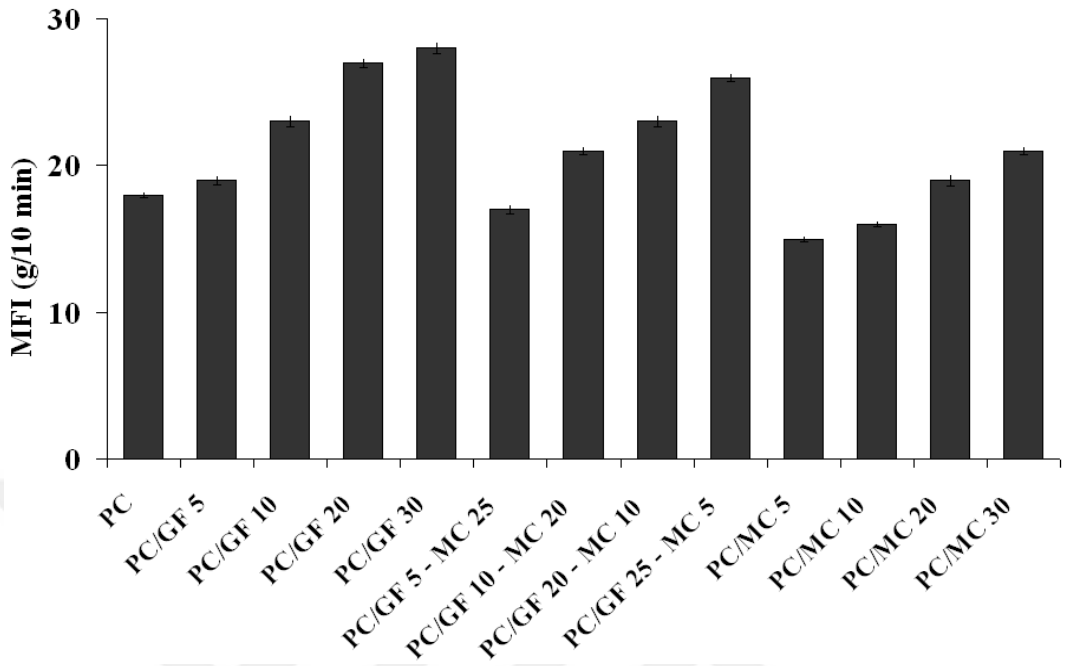

Figure 14. Melt flow index results of PC and its composites

As represented in Figure 14, MFI results show that the addition of GF into PC increased the melt flow rate. This improvement was observed obviously for higher GF loaded composites. The MFI value decreased with addition of 5% and 10% mica to PC matrix. However, the higher level of mica contents caused increasing in MFI values. Observation of lower MFI values of PC/MC composites relative to PC/GF ones may be related with layered structure of mica particles which have larger surface area [32, 33]. In the case of hybrid composites, MFI results were almost averages of PC/GF and PC/MC composites. For the hybrid composites, the MFI value increased with GF inclusions and decreased with mica additions.

3.4 DSC Analysis

The DSC curves of unfilled PC, PC/MC, PC/MC-GF hybrid and PC/GF composites are shown from Figure A.1 to Figure A.12 located in Appendix part and the relevant DSC analysis data are listed in Table 4.

It can be seen from Table 4 that T_g of the 5% mica containing composite were slightly higher with respect to T_g of PC, and they generally shift to informed lower temperatures with the further addition of mica. The inclusion of glass fiber in PC caused improvement for T_g of pure PC. Increase in T_g carried on from 5% to 20% GF concentration, then sharp decrease was observed for PC/ 30% GF composite. T_g of hybrid composites were almost identical at all of the compositions investigated. Hybrid composites gave slightly lower T_g values as compared with GF filled composites.

Table 4. DSC results of PC/GF composites

SAMPLE	**T_g (^{0}C)**
PC	141.53
PC/5% GF	142.49
PC/10% GF	142.64
PC/20% GF	143.01
PC/30% GF	140.75
PC/5% MC 25% GF	141.04
PC/10% MC 20% GF	141.57
PC/%20 MC 10% GF	141.41
PC/25% MC 5% GF	141.77
PC/5% MC	142.41
PC/10% MC	141.68
PC/20% MC	141.55
PC/30% MC	141.80

3.5 SEM micrographs

Morphological investigations of composites were performed by using SEM micrographs of composites. Distributions of added fillers were examined with the help of SEM images of fractured surfaces of composites.

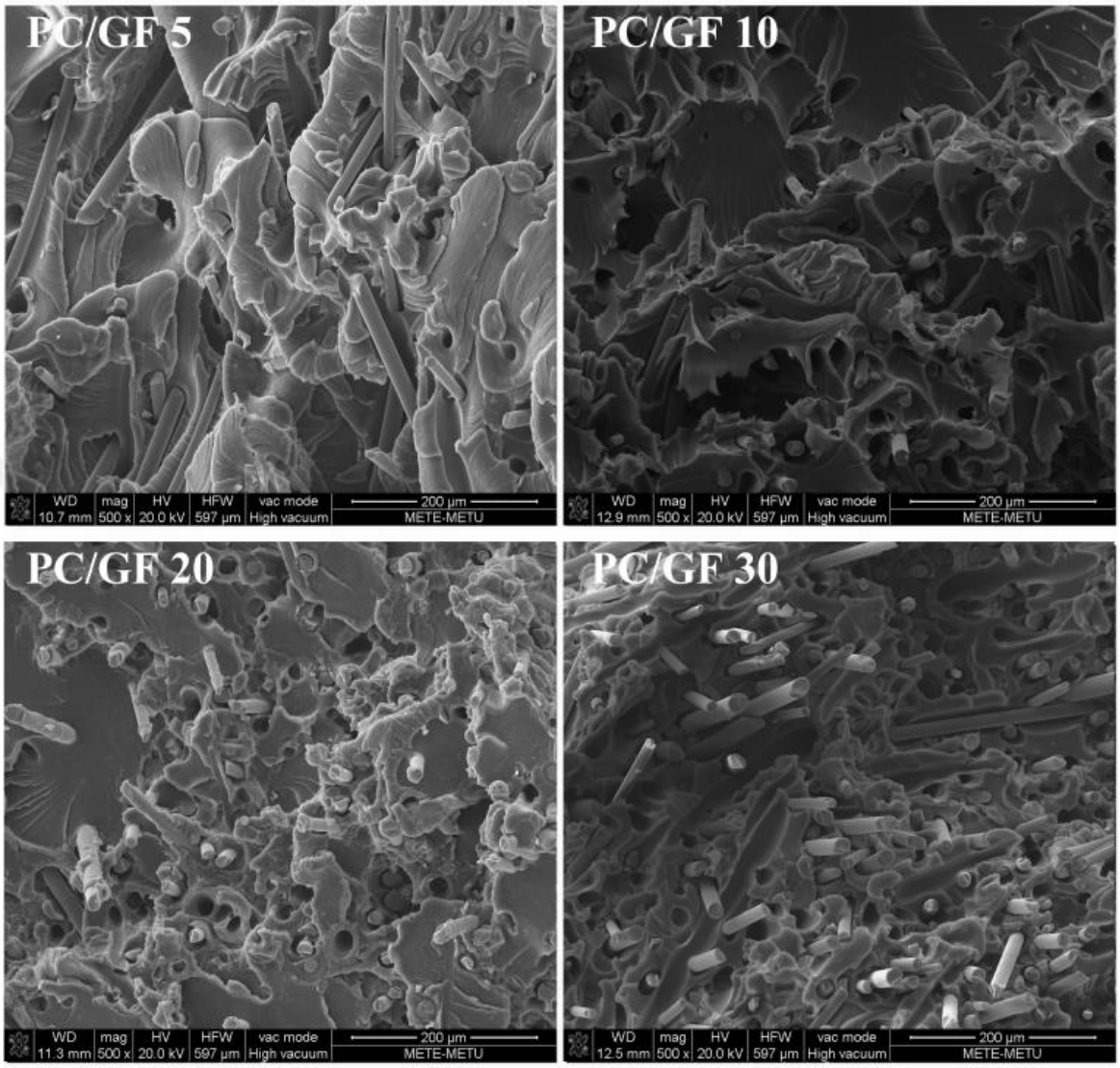

Figure 15. SEM images of PC/GF composites.

According to SEM micrographs of PC/GF composites in Figure 15, fibers were homogeneously dispersed in the lowest GF containing composite. As the concentration of GF increased bundle formations of fibers were observed. The distribution of GF in PC matrix is more homogeneous for PC/GF20 than PC/GF30. The distributions of GF for given percentages were in agreement with mechanical tests results discussed in earlier sections in which 20% concentration is the optimum value for GF loaded PC composites.

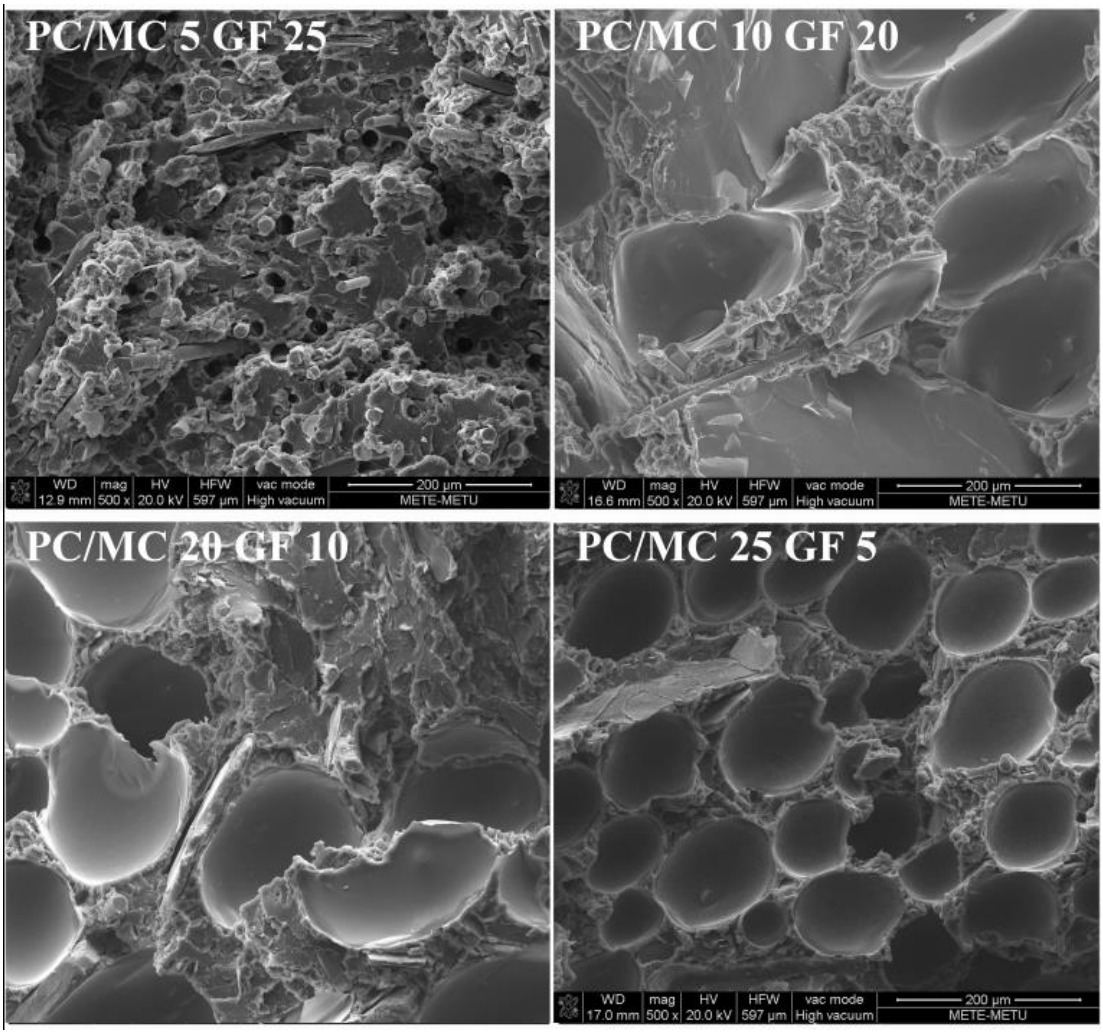

Figure 16. SEM images of PC/GF-MC hybrid composites.

The investigation of scanning electron micrographs of hybrid composites in Figure 16 shows that the most homogenous distribution was observed for 5% mica and 25% GF filled PC composites. The agglomerations were seen dominantly as mica content increased, especially for 20% and 30% mica containing hybrid composites.

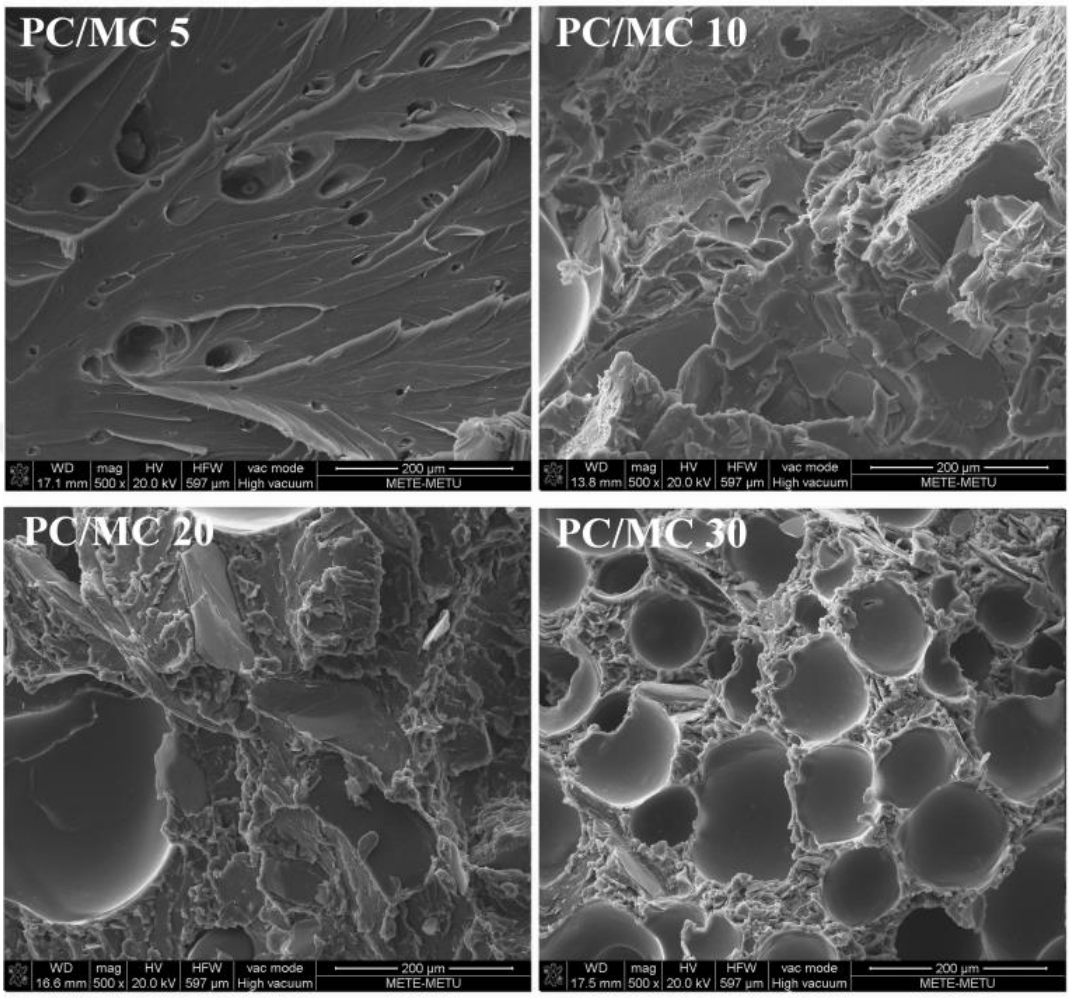

Figure 17. SEM images of PC/MC composites.

As seen in Figure 17, the lowest mica loaded composite showed homogeneous distribution of mica particles in PC matrix, but as mica content increased about 20-30% agglomerations started to dominate. Mica particles exhibited the tendency of adhesion to each other rather than interaction with polymer matrix. This observation may also be caused from the inert surface of mica for PC that results with incompatibility.

CHAPTER 4

CONCLUSION

In this study glass fiber and mica were added to polycarbonate matrix individually and together in hybrid form. Processing methods were chosen as melt mixing and injection molding for the purpose of practical adaptation to large scale composite applications. The mechanical, flow, thermal and morphological characterizations of produced composites were examined via tensile test and impact test, melt flow index test, differential scanning calorimetry analysis and scanning electron microscopy techniques, respectively.

The overall results revealed that the optimum values for mica containing, glass fiber reinforced and hybrid forms were found as 5%, 20% and 25% GF-5% MC filling ratios, respectively. The maximum tensile test values (tensile strength and Young's modulus), impact strength and glass transition temperatures estimated from DSC were obtained in these optimum compositions of composites. The further additions of these fillers caused agglomerations for mica particles and bundle formations for glass fibers according to SEM micrographs. Such formations resulted in restriction of their homogeneous distribution in the PC matrix.

MFI test results exhibited that mica filled composites gave lower MFI values compared to the glass fiber containing ones attributed to higher surface area of mica particles.

Even though main target was to obtain better overall properties in the case of hybrid forms, individual additions of these fillers resulted in higher mechanical properties.

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APPENDIX

A.1. DSC curves of PC and its composites

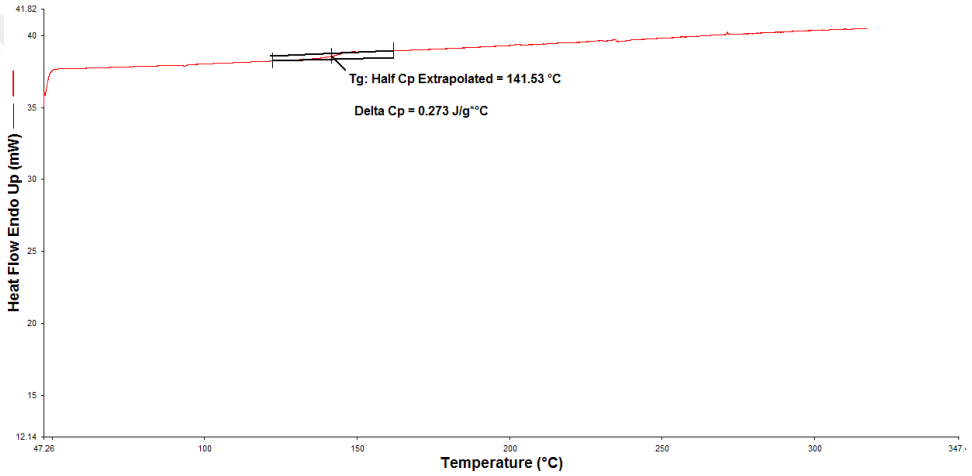

Figure A. 1 DSC curve of unfilled PC

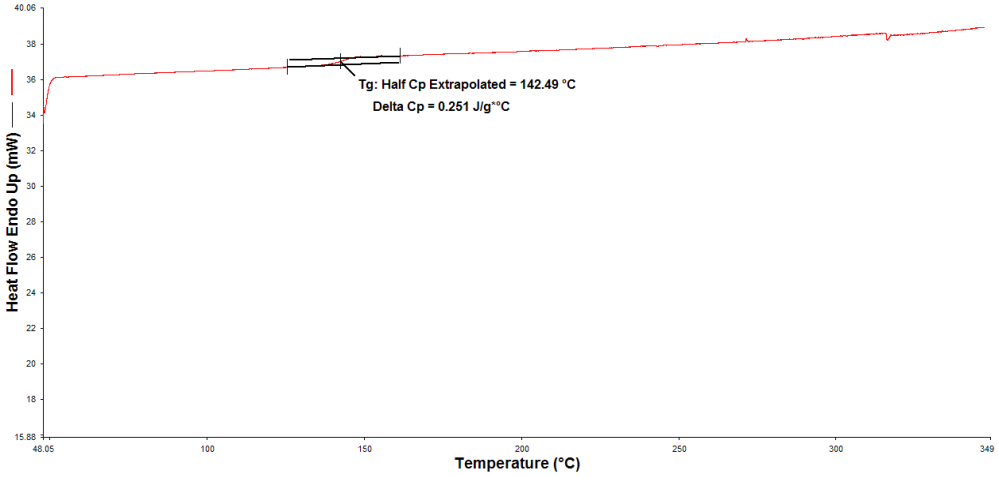

Figure A. 2 DSC curve of PC/5% GF composite

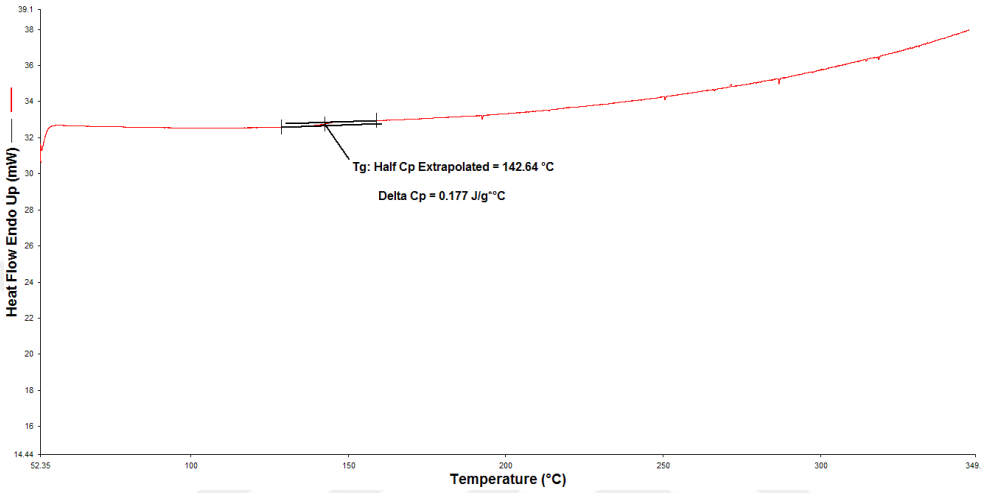

Figure A. 3 DSC curve of PC/10% GF composite

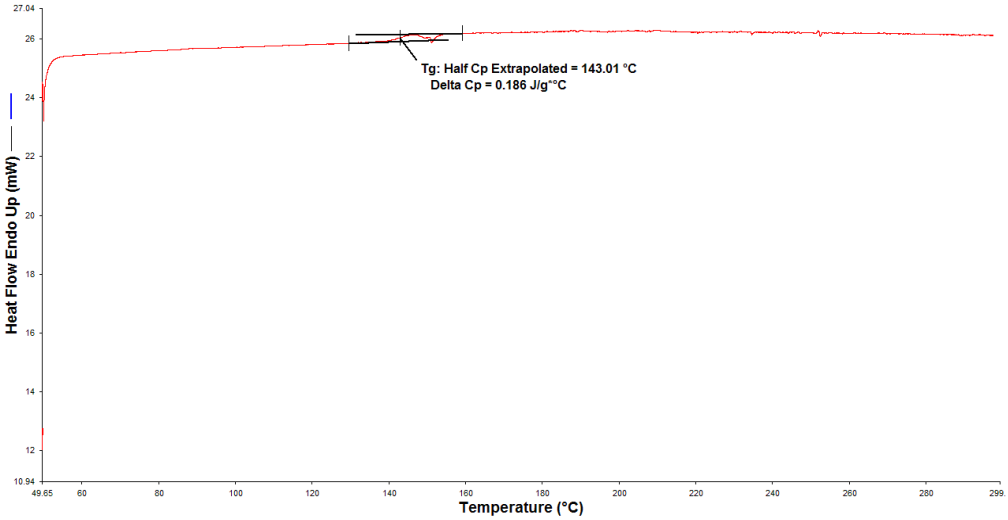

Figure A. 4 DSC curve of PC/20% GF composite

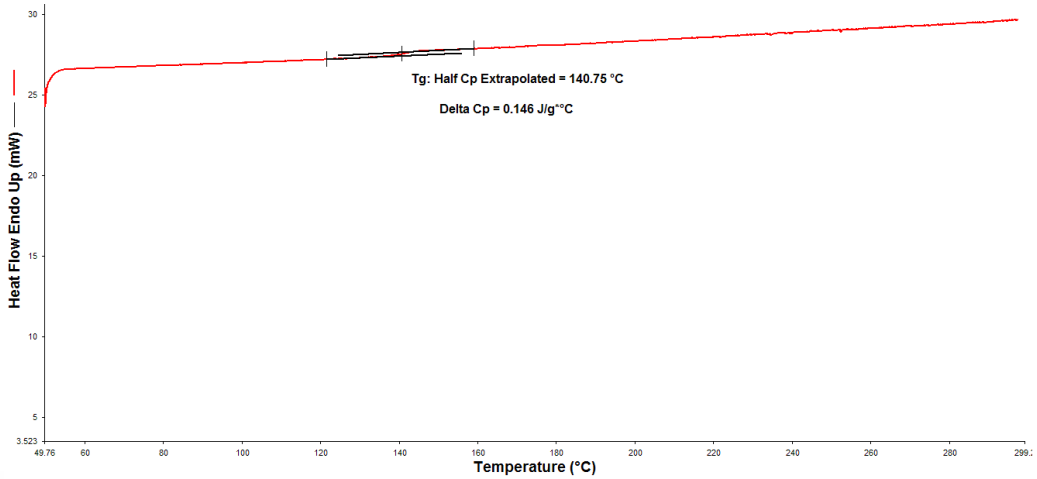

Figure A. 5 DSC curve of PC/30% GF composite

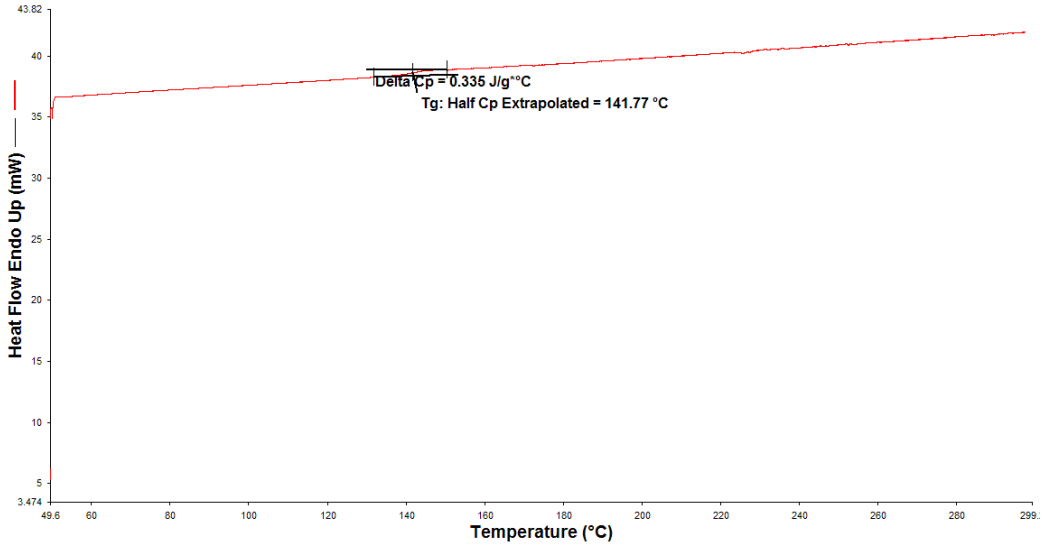

Figure A. 6 DSC curve of PC/5% GF 25% MC hybrid composite

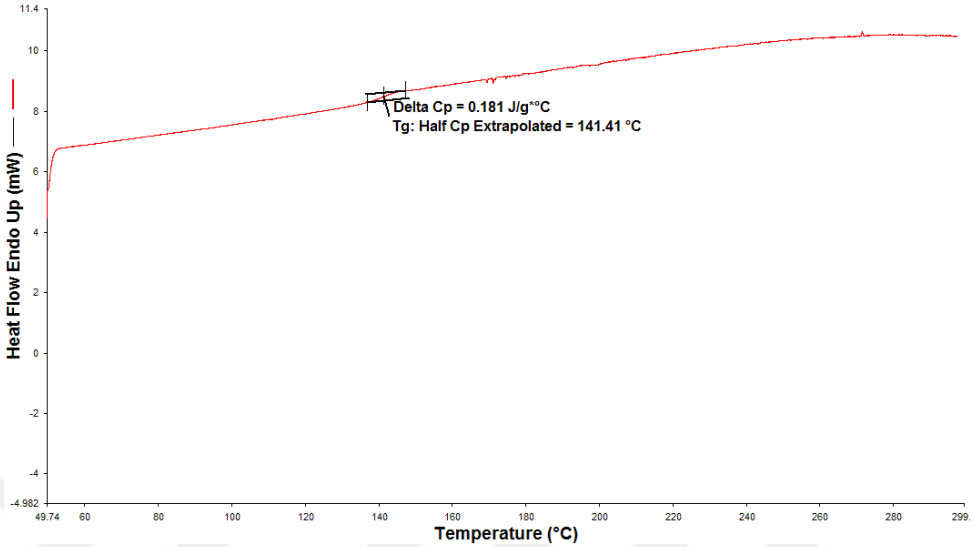

Figure A. 7 DSC curve of PC/10% GF 20% MC hybrid composite

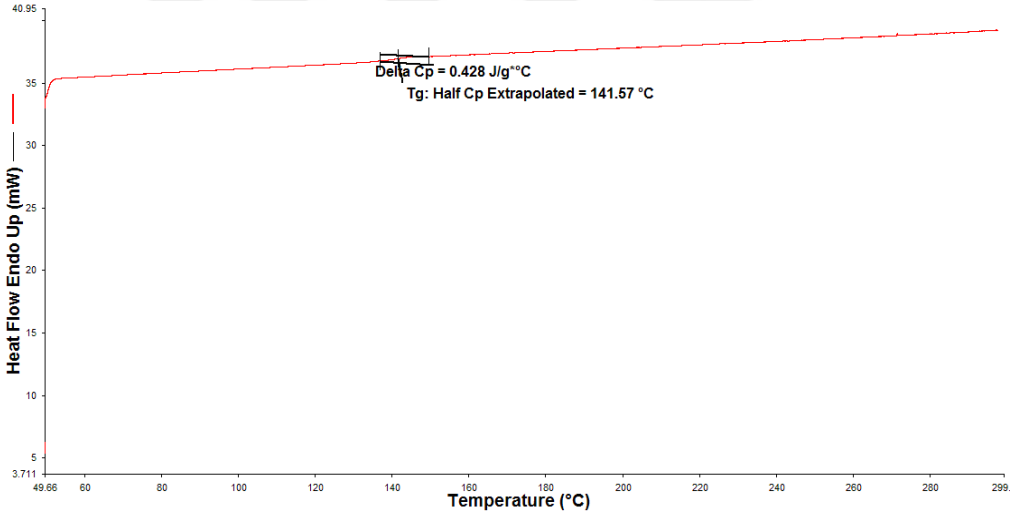

Figure A. 8 DSC curve of PC/20% GF 10% MC hybrid composite

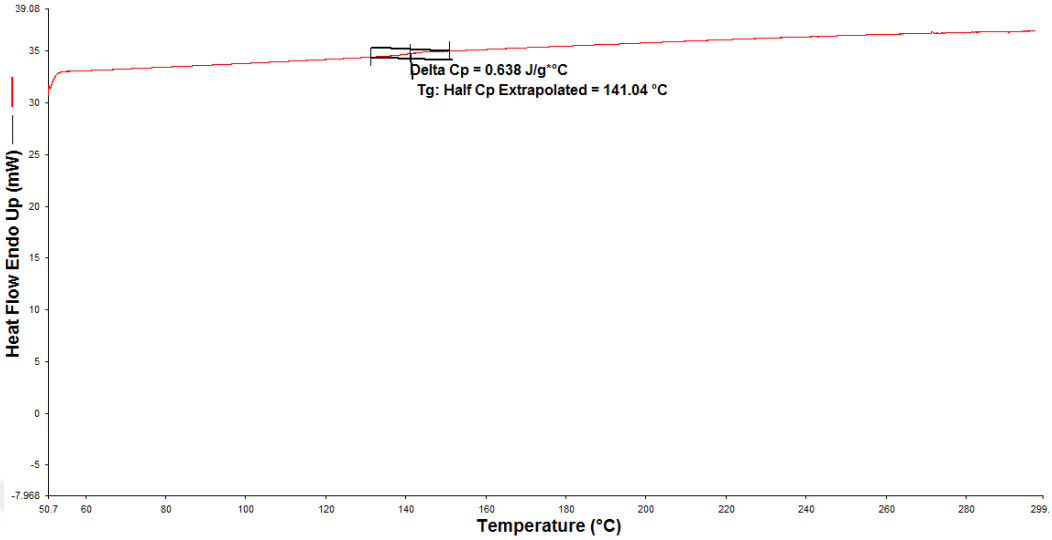

Figure A. 9 DSC curve of PC/25% GF 5% MC hybrid composite

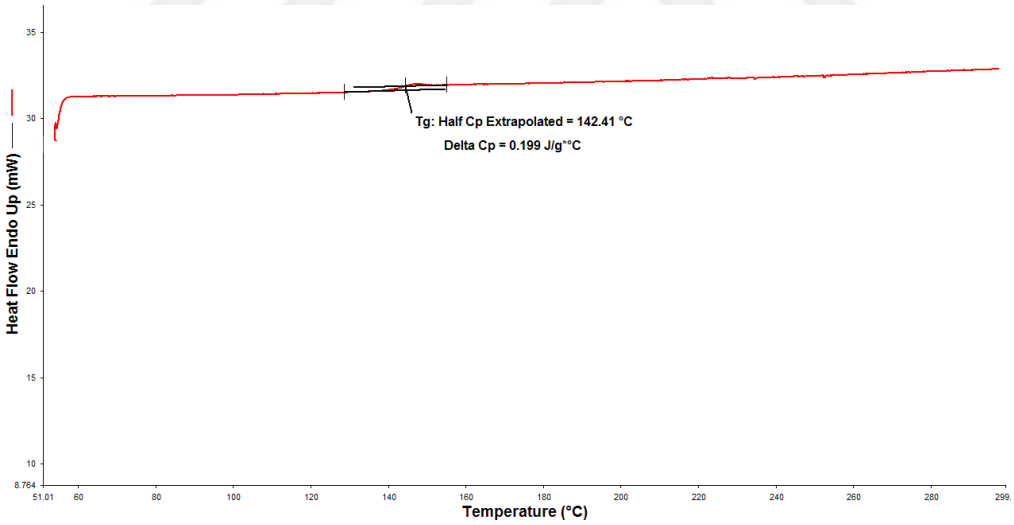

Figure A. 10 DSC curve of PC/ 5% MC composite

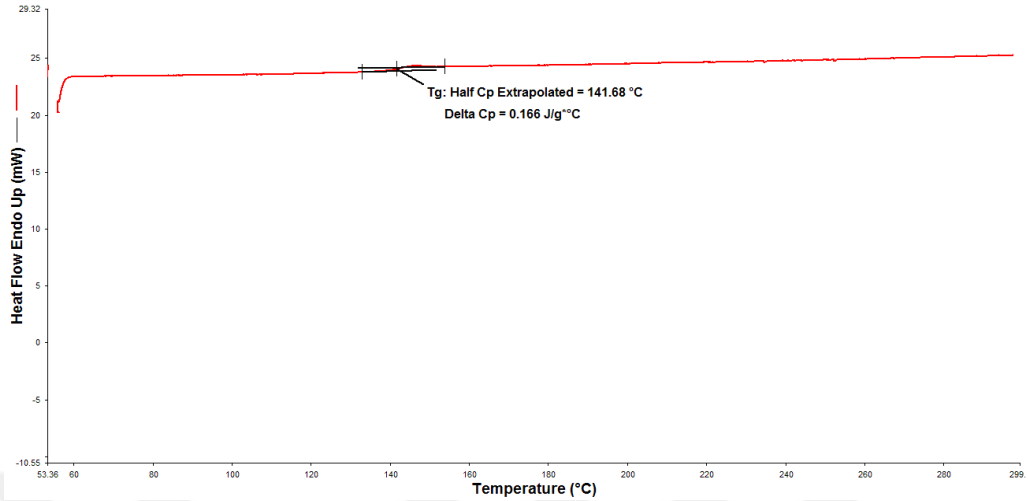

Figure A. 11 DSC curve of PC/ 10% MC composite

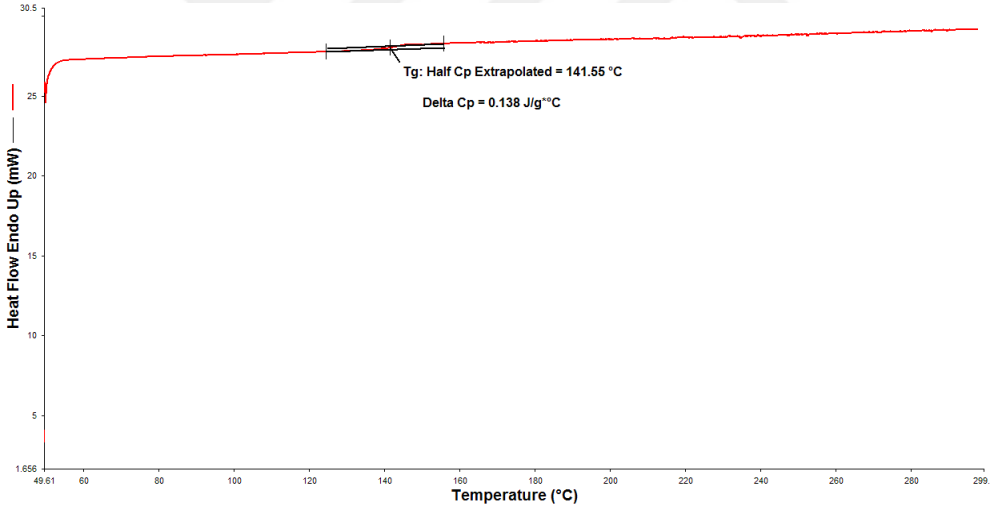

Figure A. 12 DSC curve of PC/ 20% MC composite

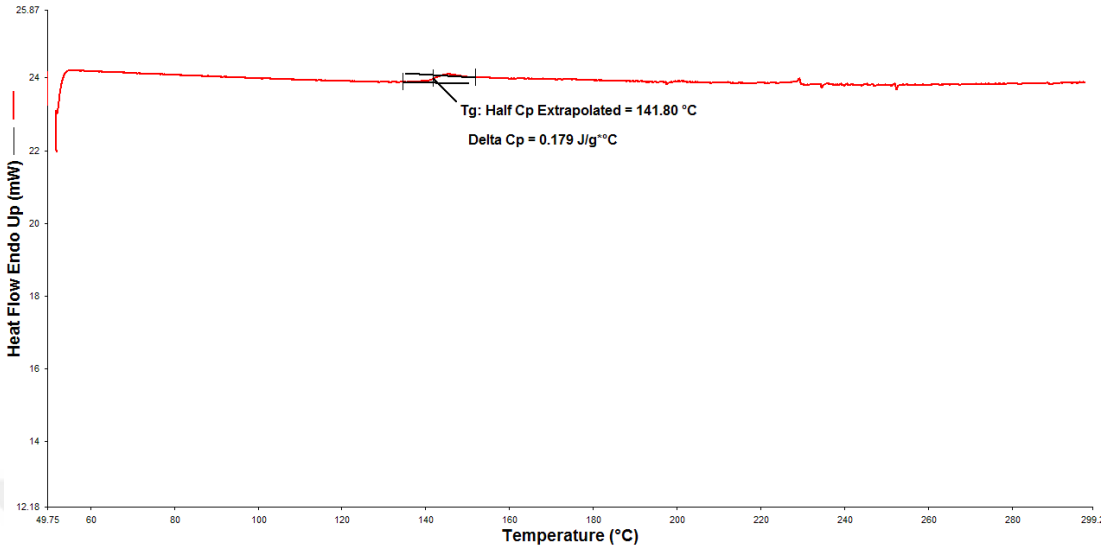

Figure A. 13 DSC curve of PC/ 30% MC composite