Mechanical and Thermal Behavior of PP-PET Blends

Ashish R.Thakre[1], Dr.R.N.Baxi[2], Dr.P.V.Walke[3], Pratibha Gupta [4]

[1]Research Scholar, Department of Mechanical Engg,G.H.Raisoni College of Engg,Nagpur
[2]Ex. Professor, Department of Mechanical Engineering, G.H.Raisoni College of Engineering, Nagpur.
[3]Professor and Head, Department of Mechanical Engineering, G.H.Raisoni College of Engineering, Nagpur.
[4]R&D Associate ,Hytec Resistors Pvt.Ltd,Nagpur

Abstract – *In this study , mechanical properties and thermal properties of the PP-PET blends of different concentration (up to 50% PET) are evaluated predominantly. Addition of PET is found beneficial as far as enhancement in the Mechanical properties is concerned. However, immiscibility is reported in every synthesized composition. This was predominantly observed in DSC analysis. This experimentation thus served the purpose of pilot experimentation for selecting proper composition/PET concentrations in PP for compatibilization in future studies.*

Keywords- PP, PET,DSC,PP-PET blend, Izod Impact strength.

INTRODUCTION

Steep growth in production of Polypropylene and its use is well known during last few decades. Polypropylene is popularly being used in various sectors of industry such as Chemical , Electrical, Automotive , household, textile, agriculture, packing,transportation and many more. Market consultancy and management research indicated that PP witnessed robust growth during last decade and also forecasted that demand of PP is likely to crossover its 4-5% average annual growth rate of past decade in the near future [1]. It is worth mentioning that technological development in material designing and subsequent research and development are the important driving parameters for such steep rising consumption of this commodity resin. *Hisham A. Maddah* in his recent studies mentioned the promising nature of this PP as polymeric resin and indicated that the vast number of applications from PP showed that it is ideal choice among all other resin polymers to produce flexible, long lasting, cost effective and light weight material for numerous industrial sectors as mentioned above [2]. Blending with polypropylene is extensively being studied during developmental stages of this resin material by different researchers. Polypropylene blended with resins from polyester family to enhance engineering characteristics was also studied extensively. In one of such studies *G.M.Shashidhara et. al*.synthesised Polypropolyne copolymer and nylon 6 blend using PP-g-MAH compatibilizer.Mechanical properties especially tensile strength was found to get improved in the blends. This result was also supported by TEM studies of the same blends. Discrete domains of the nylon 6 were absent in PPCP-g-MAH-Nylon6 blends indicating miscibility. In this studies no significant improvement in the thermal properties were reported [3]. In similar such studies by *Mehdi Afshari et.al.*on bulk propertis of PP-Nylon 6 blends rheological properties of polyblends were studied and also correlated them with DSC analysis and SEM studies.PP-g-MAH was used for compatibilization. It was observed that as amount of PP-g-MAH in 80/20 blends increased, the apparent viscosity at low shear rates increased. Spinnability of polyblends into fibres showed unstable condition during the spinning of the blends 45/50/5 composition. In rest of the blends polyblend fibres were mechanically robust.[4] In one another study of PP-polyester blends, *Somit Neogi et.al.* studied wear properties of PP-PET in sliding dry condition. Four different compositions of PP-PET were studied to examine wear behaviour.It was reported by the researchers that addition of PET improves wear resistance of PP by reducing the wear loss. SEM observations of the worn surfaces indicated that PET balls which were seen evenly distributed before wear test were found removed leaving pits at worn surfaces. The significant plastic deformation was not observed on PET balls and grooves were found without wedge formation. The absence of plastics deformation clearly shows the better wear performance of PET as compared to PP[5].This might have contributed to the result of improvement in wear resistance of PP-PET blends. In the view of the challenges of the disposal of the PET *Renato Carajelescove et. al.* prepared blends of PP-recycled PET fibres using PP-g -MA compatiblizer using 2^2 multiple regression statistical analysis. Besides tensile test and impact tests Fatigue tests indicating response of the surface to the tensile fatigue was studied in this work. Heat deflection tests indicated increased thermal stability promoted by recycled PET fibre. Overall result of this research shows that recycled PET fibre can be used as reinforcement in polypropylene when they are compatibilized up to 4 wt %.[6] Slightly rare literature regarding absorptive and barrier properties of PET/PP blends investigated by *Tadashi Otsuka et.al.* The study was in the interest of pharmacutical sector especially for eye drop containers. PP/PET blends were studied without compatiblization in the view of safety issues. Except 70/30 and 50/50 PET/PP blends rest of the blends were found to bear the experimental load required for eye drop containers. Although 50/50 PET/PP and 70/30 PET/PP blends showed the most favourable balance in moisture vapor transmission rate and antiadsorptive properties of L-menthol, however, poor mechanical characteristics were major concern in these blends[7].Dual compatiblization using maleated PP and epoxy resin was studied by *G.N.Onyeagoro et.al.* In this work one of the constituents is bio polymer and PP and PET used were post consumer in nature. This has lead a step in the direction of green technology. Superior interfacial adhesion was observed in this study upon the addition of EPR [8]. In similar initiative of protecting environment *A.Elamri et.al.* studied and characterized recycled PET polymers of different grades and compared with virgin resin material. Even though recycled PET has relatively low molecular weight, right blending it with virgin material helped in upgrading the properties of recycled material for the noble cause of reusing the same. Both virgin PET and recycled PET were miscible down to macromolecular level as was clear from morphological and thermal properties [9]. The review of mechanical properties of polypropylene carried by *Quazi T.H.Shubhra et.al.* identified that reinforcement of PP by various fibres like E glass fibres (synthetic) and flax (natural) receiving very much attention. This fibre reinforced polymers were very strong when the surface of fibres modified by the treatments like alkalization, oxidation or diazotization [10].

The present work is the part of the material development of PP and PET composites. PP and PET blends in different proportions are synthesised in the present study. These blends are uncompatiblized mainly to verify the miscibility of these two resins. Mechanical and Thermal behaviour of the blends is studied in the present study. The objective of this work is to identify the best composition or compositional range of the constituents for further research work.

Experimental work:

Materials and methods

Material- Homopolymer polypropylene (11 MFI,density 0.905 Gm/ml ,Grade PP 110 MA Homopolymer PP of Reliance Ltd.India.) and Polyethylene Terephthalate (density 1.364 Gm/ml) was obtained from PET Brand WK – 801 Std Q/WK 007-2016 of Zhejiang wankai new material co.Ltd were used to synthesis different blends Table 1 shows the detailed compositional features of these materials.

Five types of blend materials along with two virgin polymers were investigated in this study as mentioned in Table2

Table-1-Typical Properties of the Polymer used in this study

Property	**Unit**	**Typical Values**	
		PP	**PET**
Tensile stress at break	Mpa	35.31	40.79
% Elongation at yield	%	7.2	5.2
Density	Gm/ml	0.905	1.364
Melt flow index(260 ^{o}C/2.16Kg	Gm/10 minute	11	0.05
Izod Impact strength	J/m	22.18	19.44
Vicat Softening Point	^{o}C	122	226.0
Tensile Modulus	Mpa	196.63	202.36
Hardness	Shore D	64	72

Table-2 -Compositional features on newly synthesized blends Designation of blend % PP % PET

Sr.no	Blend Code	Wt %	
		PP	PET
1	3PET1	50%	50%
2	3PET 2	60%	40%
3	3PET3	70%	30%
4	3PET4	80%	20%
5	3PET5	90%	10%
6	Virgin PP		
7	Virgin PET		

Method of blending : The test specimen were prepared using SM90HC 90T Injection Moulding Machine

Material Testing : All test were performed at room temperature 24 ± 2°C and 50-55 % Relative Humidity

a) Tensile Stress at Break , % Elongation and Tensile Modulus - Moulded test specimen (Dumbell Shaped) as per ASTM D638 is used for tensile test. With a cross head speed of 50mm/min, Test performed until the specimen break. Five specimens are tested and results are reported as an average of five observation.

b) Melt Flow Index(260 °C /2.16kg)- Test procedure per ASTM D1238 is adopted for Melt Flow Index. The test is carried out at 260°C barrel temperature with applied pressure via load of 2.16Kg is applied vertically and extrude are cut at the internal of 1 min and approximately 20 extrude are cuts for one composition, and reported results is an average ten similar weights of extrude.

c) - Izod Impact Strength- Test specimen as per ASTM D256 is prepared for Izod Impact .Test is performed until the specimen is break. Five specimen are tested and results are reported as an average of five observation.

d) Vicat Sofetning- As per ASTM D256, Vicat Sofetning Test is carried out . Instrument used Vicat Sofetning is of M/S International Equipment Mumbai, India, Method A under 1.0 Kg load applied , three measurement are done and reported result is an average of three observation.

e) Hardness- Hardness measurement is performed as per ASTM D2240. Minimum five observation are taken at same specimen and reported results is an average of five observation.

f) Density - Specimen are tested as per ASTM D792. Minimum three observations are taken at same specimen and a reported result is an average of three observations.

g) Differential Scanning Calorimeter- Thermal characterization is done using Mettler Toledo, DSC with following Specifications

Gas atmosphere: Nitrogen

Reference sample: Aluminium

Heating Rate: 10 ^{o}C/min.

h) X Ray Diffraction- XRD measurements were carried out using Bruker D8 Advance X-ray diffractometer. The x-rays were produced using a sealed tube and the wavelength of x-ray was 0.154 nm (Cu K-alpha). The x-rays were detected using a fast counting detector based on Silicon strip technology (Bruker LynxEye dtector).

RESULT AND DISCUSSION

Table-3 Physical Properties of virgin PP virgin PET and newly synthesized blends.

Blend Code	Density gm/ml	
	Theoretical	Experimental
Virgin PP	0.85	0.90
3PET1	0.85	0.86
3PET2	0.86	0.94
3PET3	0.86	1.03
3PET4	0.86	1.03
3PET5	0.86	1.08
Virgin PET	0.86	1.36

Physical Properties: Density measurement of all the newly synthesised blends and their constituents are shown in Table 3. It is observed from the results that with the addition of PET gradually the density go on steadily reducing and blend 3PET1 is
having density lower than both the constituents. Specific strength of the material is always a key issue any product designing. PP-PET blends indicate this feature as clear from the results. Refer table4.

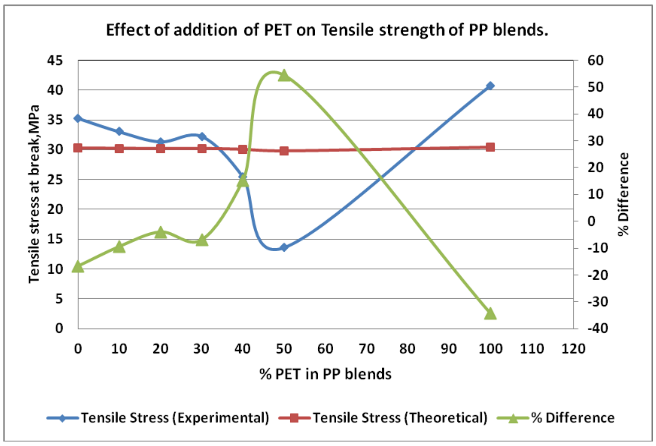


Fig 1- Effect of addition of PET on Tensile strength of PP-PET blends

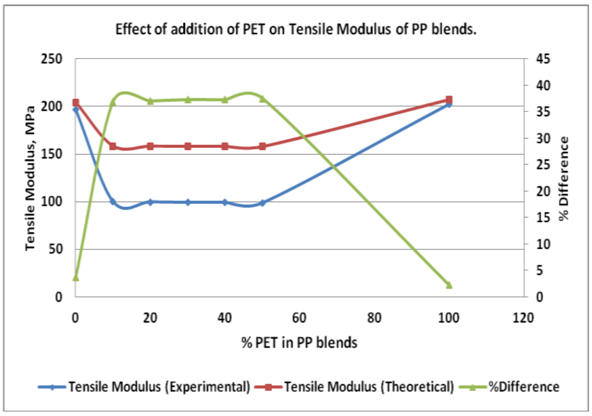


Fig 2-: Effect of addition of PET on Tensile modulus of PP-PET blends

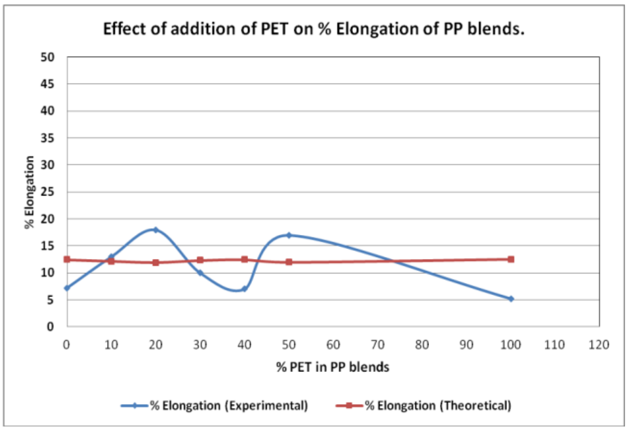


Fig 3- Effect of addition of PET on % elongation of PP-PET blends

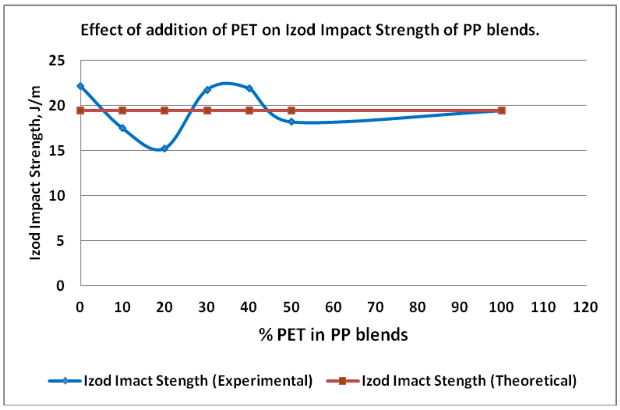


Fig 4- Effect of addition of PET on Izod impact strength of PP-PET blends

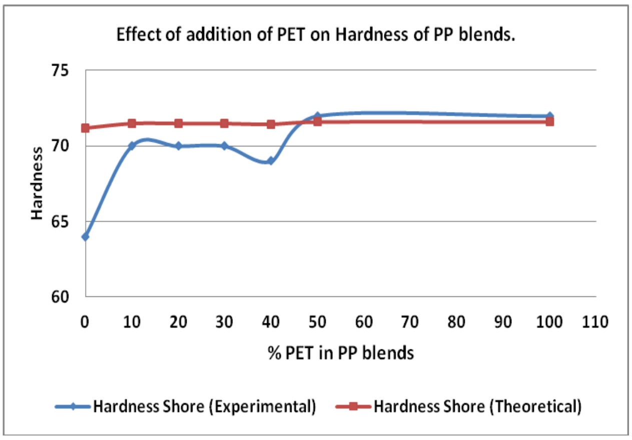


Fig 5- Effect of addition of PET on Hardness of PP-PET blends

Mechanical properties of the synthesized PP-PET blends are shown in Table 4. From the experimental values of tensile strength, % elongation and tensile modulus of different PP-PET synthesized blends, it is clear that the tensile strength of all the blends is found to get lowered by the addition of PET. However, blends beyond 30% PET showed tensile strength comparable to that of virgin PP. The theoretical value of a property of a blend are calculated from the rule of mixtures. Theoretical values of the tensile strength of these blends are also very much closer to the respective experimental value except 3PET4 and 3PET5. Blend 3PET4 and 3PET5 showed poor tensile strength value indicating lack of compatibility in blending. Figure 1 shows effect of addition of PET on Tensile strength and graph based on theoretical values superimposed on it. If the blend components are compatible with each other, the theoretical value of the property will be in close agreement with that of experimental value. The dual phase nature of the blend as reported by Somit Neogi et.al.[5] might be responsible for such a behaviour. The tensile modulus drop in all the blends supported the values of experimental tensile strength. The same is shown in figure 2. The immiscibility of the constituents might be responsible for such a behaviour. % elongation results are superior than both the virgin material. Figure 3 indicates this behaviour of the blends. The chains of the polymers might be in the twisted condition and they must be getting straightened in the direction of stress thus showing strong elastomeric nature. Amongst all the blends 3PET5 is most rubbery in nature. The izod impact value supports this behavior of almost all the blends. The izod impact values is almost approaching to that of izod impact value of virgin PP in case of 3PET4and 3PET3 blends. The same is proved theoretically in Figure 4. Hardness of virgin PET is more than that of virgin PP. Hardness values of all the synthesized blends are more closer to virgin PET. Graphical presentation of the hardness values of the blends and virgin materials is shown in figure 5.

Table5 Thermal Properties of virgin PP virgin PET and newly synthesized blends

Blend Code	Melt Flow Index gm/10min		Vicat Softening ^oC	
	Theoretical	Experimental	Theoretical	Experimental
Virgin PP	29.65	11	225.72	122
3PET1	40.30	28.56	218.34	115
3PET2	55.07	52.92	221.50	118
3PET3	48.48	42.05	223.61	120
3PET4	55.69	53.95	223.61	120
3PET5	47.46	40.38	225.72	122
Virgin PET	23.00	0.05	335.42	226

Table-4 Mechanical Properties of virgin PP virgin PET and newly synthesised blends.

Blend Code	**Tensile strength Mpa**			**Tensile Modulus Mpa**			**% elongation**		**Izod Impact Strength- J/m**		**Hardness**	
	Theoretical	**Experimental**	**% difference**	**theoretical**	**Experimental**	**% difference**	**theoretical**	**experimental**	**theoretical**	**Experimental**	**theoretical**	**experimental**
Virgin PP	30.25	35.31	16.70	204.25	196.63	3.73	12.46	7.2	19.46	22.18	71.15	64
3PET1	30.21	33.05	-9.40	158.41	99.96	36.89	12.17	13	19.47	17.49	71.48	70
3PET2	30.17	31.36	-3.93	158.30	99.73	37.00	11.93	18	19.47	15.27	71.48	70
3PET3	30.19	32.27	-6.88	158.02	99.15	37.25	12.32	10	19.46	21.76	71.48	70
3PET4	30.05	25.48	15.20	158.03	99.17	37.24	12.47	7	19.46	21.91	71.43	69
3PEt5	29.80	13.58	54.43	157.78	98.63	37.48	11.98	17	19.47	18.2	71.60	72
Virgin PET	30.37	40.79	34.31	206.96	202.36	2.22	12.56	5.2	19.47	19.44	71.60	72

Table 6 Differential Scanning Calorimetric results of virgin PP virgin PET and newly synthesized blends.

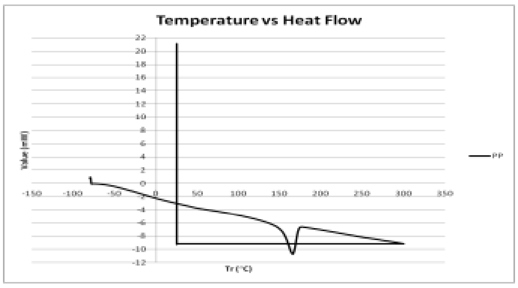
Blend Code	**Tg**		**Melting point**		**Melting point**	
	X(Tm)	**Y(Mw)**	**X(Tm)**	**Y(Mw)**	**X(Tm)**	**Y(Mw)**
Virgin PP	-78.414	-0.153	165.806	-10.754	---------	---------
3PET1	27.688	-1.426	164.317	-7.445	251.613	-3.9
3PET2	28.764	-1.07	164.641	-1.609	251.553	3.05
3PET3	27.864	-1.466	163.414	-6.443	250.49	-4.185
3PET4	28.389	-1.536	163.584	-6.103	251.354	-4.549
3PET5	-78.414	-0.153	165.806	-10.754	---------	---------
Virgin PET	27.663	-1.24	249.536	-5.59	---------	---------

Table:7 Table showing XRD details of virgin PP virgin PET and newly synthesized blends.

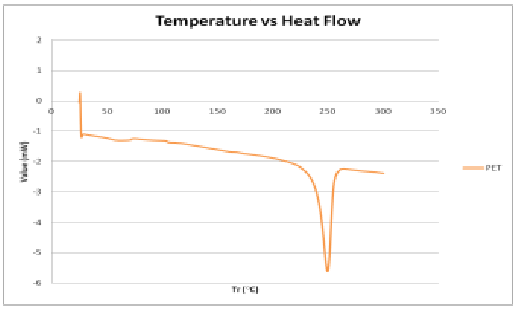
Blend Code	PEAK 1		PEAK 2		PEAK 3		PEAK 4		PEAK 5		PEAK 6		PEAK 7	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
Virgin PP	17.84	1865	22.88	1983	26.09	2102	42.702	5273	17.84	1865				
3PET1	14.27	8285	17.11	6123	18.70	.466	22.008	5225	25.64	1534	28.71	1201	42.93	
3PET2	14.27	7341	17.08	5646	18.74	4471	21.863	4774	25.81	0.16	28.72	1165	42.64	
3PET3	14.30	5968	17.14	4647	18.61	3779	21.89	0.39	25.66	1716	42.79	793.27		
3PET4	14.18	4659	17.04	4202	18.58	3458	21.631	3753	25.32	1814	28.58	1168	42.77	
3PET5	14.17	4142	16.98	4035	18.65	0.33	21.814	0.31	25.58	2179	42.88	814.83		
Virgin PET	14.29	7347	17.12	4983	18.66	3826	21.763	4052	25.67	1034	28.68	908.56	42.88	757.67

Thermal Properties: Rheology related characteristics of the virgin materials and newly synthesized blends are reported in the Table 5. It is observed that melt flow index of the blends is getting raised by the addition of PET. Absence of continuity in the chains of the blended material is obvious from this result. It is studied by Bremner, T.; A. Rudin [11,12] that there is inverse relation of molecular weight and MFI.The same was formulated by the authors as follows ($1/MFI = GMx^{w}$) where,G is shear modulus and Mx^{W} represents molecular weight. High extrusion rates and long injection lengths can be expected from these blends since viscosity seems to be lower from the values of the MFI observations of the newly synthesised blends. However, tendency of the flow as Newtonian fluid cannot be denied.

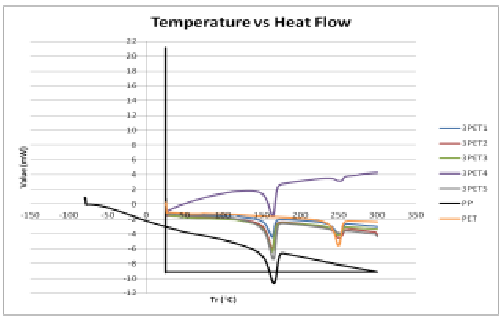
Addition of PET in PP reduces the softening temperature as is clearly seen in the Table 5. When compared with virgin PP, slight lowering of vicat softening temperature is noted. Thus, it can be stated that thermal stability is marginally getting lowered with the addition of PET.



(a)



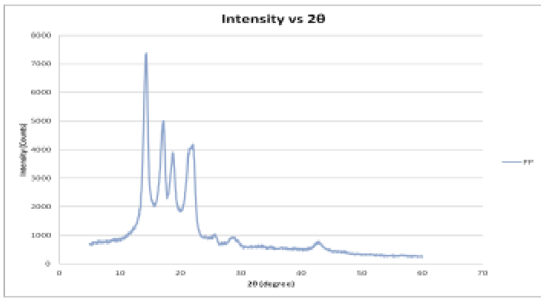
(b)



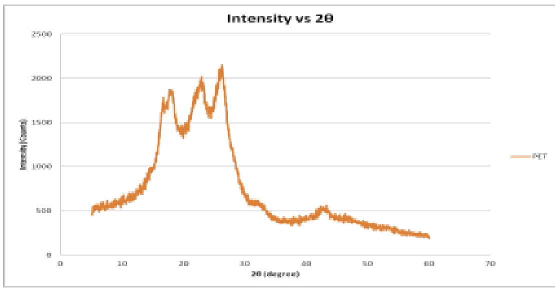
(c)

Figure 6 (a), (b) and (c): Graphs showing DSC results of the Virgin PP, PET and PP-PET blends

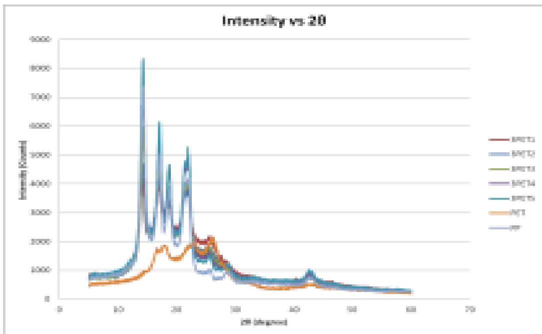
DSC studies of virgin materials blends are shown in figure 6 . Figure 6(c) shows two separate endothermic peaks is an indication of immiscibility of the constituents. Corresponding values of the melting points of the constituent materials is reported in the Table 6. These results are complementary to the mechanical properties as described above and the dual phase nature of the blend is evident from these results.



(a)



(b)



(c)

Figure 7 (a), (b) and (c): X Ray Diffractograph of virgin PP virgin PET and newly synthesised blends.

Structural Properties: Morphological features of the virgin materials and blends is seen in figure 7.Semicrystalline nature of the virgin polymers is observed. Characteristic peak positions in virgin PET are reported in Table7 Slight change in the peak position in case of the blends is noticed when compared with virgin materials. It is also observed that the peak positions of the all the synthesised blends are closer to that of virgin PET. The blends are indicating semi crystalline nature and new bonds structure is clearly expected from the observations of different peak positions of the newly synthesized blends.

CONCLUSION

This study was conducted with the aim of blending commodity resin with engineering polymer. Miscibility of the two constituents is relatively poor as concluded from tensile strength of the synthesised blends. The same was verified by thermal studies using DSC. Semicrystalline behaviour of the blends gives indication for scope of enhancing mechanical characteristic of PP-PET blends. The compatibility of the blends need to be enhanced using suitable compatibliser. It is concluded specifically that, PET concentration above 30% is needed to enhance mechanical properties. Tensile strength, % elongation and Tensile modulus of 3PET1,3PET2 and 3PET3 are found to be superior amongst rest of the blend composition. Blend 3PET3 is having superior impact strength over 3PET1 and 3PET2.Viscosity of all the blends need improvement and compatibilization will help in increasing the chain length which in turn will be helpful for improving kinetics of the flow properties of the PP-PET blends.

ACKNOWLEDGEMENTS

The authors are grateful to UGC-DAE Consortium for Scientific Research, Indore(MP) for giving facilities of DSC and XRD.

REFERENCES

[1] *Growth opportunities for PP resin in the Global Composite Industry,2016, Luncintel, Market research and management consulting.*

[2] *Hisham A.Maddah," Polypropylene as a Promising Plastic: A Review", American Journal of Polymer Science 2016,6(1):1-11*

[3] *G.M.Shashidhara et al,(2009), "Effect of PP-G-MAH compatibilizer content in polypropylene / nylon -6 blends."Polmer bulletin(2009),63:147-157.*

[4] *Mehdi Afshari et. al, "Effect of blend ratio on bulk properties and matrix – fibril morphology of polypropylene/nylon 6 polyblend fibers". Journal of Polymer 43(2002) 1331-1341.*

[5] *SOMIT NEOGI et. al," Role of PET in improving wear properties of PP in dry sliding condition" . Bull. Mater. Sci., Vol. 26, No. 6, October 2003, pp. 579–583. © Indian Academy of Sciences ,pp-1468-1476.*

[6] *Renato Carajelescov et al," A study of PP/PET Composites:Factorial design,mechanical and thermal properties",Journal of Polymer testing 56(2016) 167-173.*

[7] *Tadashi Otsuka et al ," Barrier , adsoptive, and Mechanical Properties of Containers Molded from PET/PP Blends for use in Pharmaceutical Solutions", Journal of Materials Science and Applications,2013,4,589-594.*

[8] *G.N.Onyeagoro et al ," Properties of Reactive Compatibilized Dika Nutshell Powder filled Recycled Polypropylene (PP)/Polyethylene Terephthalate (PET) Biocomposites using Maleated polypropylene and Epoxy resin Dual Compatibilizers" American Journal Of Engineering Research ,Volume-2,Issue-4,pp-158-169,2013.*

[9] *A.Elamri et al,"Characterization of Recycled /Virgin PET Polymers and their Composites",American Journal of Nano Research and applications,2015;3(4-1):11-16*

[10] *Quasi T.H.Shubra et al,"Mechanical Properties of polypropylene composites :A review".Journal of Thermoplastic composite material,1-30,2011*

[11] *Bremner, T.; A. Rudin, Melt Flow Index Values and Molecular Weight Distributions of Commercial Thermoplastics. J. Appl. Polym. Sci. 1990, 41, 1617-1627*

[12]*Bremner, T., Cook, D.G., Rudin, A. "Further Comments on the Relations between Melt Flow Index Values and Molecular Weight Distributions of Commercial Plastics," J. Appl. Polym. Sci. 2003, 43, 1773.*