I J M S E
© Serials Publications
8(1) 2017 : January-June • pp. 89-93

EFFECT OF REINFORCEMENT ON THERMAL AND MECHANICAL BEHAVIOUR OF RECYCLED HDPE

Narinder Singh[1,2], Rupinder Singh[1] and IPS Ahuja[2]

[1]*Dept. of Production Engineering, GNDEC Ludhiana (India), Emails: narinder3k@gmail.com, rupindersingh78@yahoo.com*
[2] *Dept. of Mech. Engineering, Punjabi University, Patiala (India), Email: ahujaips@gmail.com*

Abstract: Polymers have various applications in different fields. High density polyethylene (HDPE) and low density polyethylene (LDPE) has much more importance as these are commonly used in house hold commodities and various other applications. All these polymers are being used in its virgin state but these costs are very high. Very few studies have been put up in the field of reinforcement of metallic/ceramic particles in polymer. In this paper an effort has been made by studying the thermal and mechanical behaviour of HDPE after reinforcement of silicon carbide and aluminium oxide. For thermal behaviour differential scanning calorimeter (DSC) has been used and various values like enthalpy, melting and decomposition has been studied. For mechanical behaviour universal tensile tester has been used and tensile strength has been carried out.

Keywords: Recycled HDPE, DSC, SiC, Al_2O_3, Thermal properties.

1. INTRODUCTION

Polypropylene and Polyethylene are major component of plastic solid waste from domestic refuse [1]. Packaging is the sector with the highest volume of consumption of polymeric materials such as plastics. Although recycling of materials such as aluminium, glass, and paperboard has been rather extensively practiced, recycling of polymer materials has not reached maturity yet because of huge variety of the polymeric materials available [2]. Efforts have been made to recycle the post-consumer based plastics in order to reduce the environmental effect and consumption of virgin materials [3]. Further so many ways has been tried yet to recycle the plastic solid waste. Al-Salem, 2010 describes all of them i.e., primary, secondary, tertiary and quaternary. When plastic products are discarded after a number of life cycles, mechanical recycling techniques present themselves as a candidate for utilizing a percentage of the waste as recyclate and/or filler [4]. Mechanical recycling (i.e. secondary or material recycling) involves physical treatment, while chemical recycling and treatment (i.e. tertiary encompassing feedstock recycling) produces feedstock chemicals for the chemical industry [5]. In this present work recycling of plastic solid waste i.e., HDPE has been done by reinforcement of SiC and Al_2O_3 in different proportions. Dispersion of SiC and Al_2O_3 has been confirmed by mixing through a twin screw extruder (mini hake compounder make: Thermofisher) as it has maximum degree of dispersion. Then sample wire from this has been obtained and tested for its mechanical properties like tensile strength and elongation on universal tensile tester (UTM). After analysing the results obtained from UTM, samples were put on to differential scanning calorimeter (DSC, make: Mettler Toledo) for their thermal behaviour. After obtaining all results Taguchi L9 has been employed for further analysis of results.

2. MATERIALS AND METHODS

As stated earlier HDPE has been taken as matrix material for primary study because it is one of the majorly used material and easily available in local market in recycled form. Further HDPE has been used by many researchers by reinforcement of different particles like, talc powder, waste

printed circuit boards, recycled wood, sand, natural fibre in HDPE [6] [7] [8]. So HDPE has been collected from local recycling plant and then reinforcement of SiC (13.9 micron) and Al_2O_3 (13.9 micron) has been added to HDPE in three different proportions i.e., 10%, 20% and 30% by weight then melt flow index of single matrix material and reinforced material has been tested according to ASTM-D-1238 standard. MFI is standard test for obtaining flow behaviour of polymer [9][10]. Basis of making reinforcement in HDPE is to observe the mechanical and thermal behaviour of composite material.

3. EXPERIMENTATION

As stated earlier this research comprises of a study of thermal and mechanical behaviour of the reinforced HDPE. For this, a methodology has been drawn and shown in Fig. 1. Brief steps are illustrated below:

1. At First, waste HDPE has been collected and washed for un-contamination of polymer. Un-contamination is necessary because contamination of polymer can affect the properties of HDPE as well as reinforced material.
2. Basis of this study is to develop a wire that could be used in fused deposition modelling (FDM). However in this present work FDM wire has not been developed. Only thermal and mechanical properties of wire have been studied. For this mixing of the different ceramic particles like SiC (13.9 micron) and Al_2O_3 (13.9 micron)has been done by twin screw extruder (mini compounder). This machine ensures the high degree of dispersion of reinforcement in matrix material. Highly dispersed material from machine comes out in the form of the wire of different diameter depending upon the size of die attached.
3. After this, pallets were made for MFI testing of material. Pallets were fed in to the MFIer machine and then test was performed under defined conditions according to the ASTM standard. MFI values are shown in Table 1. All the value was made by weight.
4. After having all the values from MFIer values were further taken for analysis. Then filament wire was made with help of screw extruder machine and prepared for mechanical testing on UTM. Taguchi L9 has been employed as design of experiment. Taguchi L9 has been shown in Table 2. Table 2 shows the Taguchi orthogonal array. In this three parameter has been taken i.e., temperature, RPM and proportion of matrix material and reinforcement.

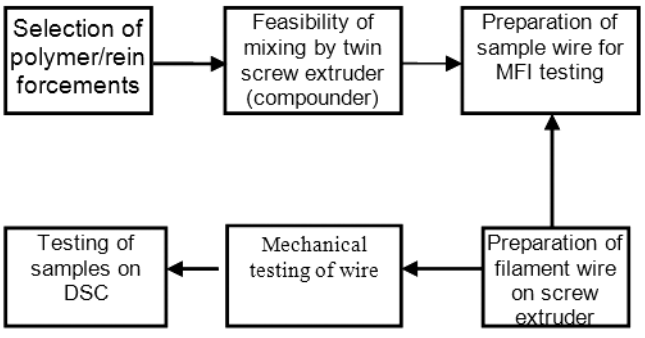

Figure 1: Flow chart for process

Table 1
Mfi Values

S. No.	*HDPE (Recycled)*	*SiC (13.9 micron)*	*Al_2O_3 (13.9 micron)*	*MFI (g / 10 min)*
1	100%	0%	0%	9.73
2	90%	5%	5%	11.47
3	80%	10%	10%	10.62
4	70%	15%	15%	11.05

Table 2
Control Log Of Taguchi L9 Experiment

S. No.	*Temp (°c)*	*RPM*	*Proportion (By weight)**
1	200	15	90%+ 10%
2	200	20	80%+20%
3	200	25	70%+30%
4	215	15	80%+20%
5	215	20	70%+30%
6	215	25	90%+10%
7	230	15	70%+30%
8	230	20	90%+10%
9	230	25	80%+20%

**Note: In first subset 90 represents HDPE by weight and 2nd subset represents equal amount of SiC and Al_2O_3* by weight.

Wire based on this Taguchi L9 has been prepared and tested on UTM for their mechanical strength. Control log of experiment has been shown in Table 3.

Table 3
Results Obtained From Mechanical Testing

S. No.	*LP* (KN/mm²)*	*PS* (KN/mm²)*
1	25.40	11.00
2	32.80	12.31
3	29.40	13.50
4	32.3	7.00
5	55	8.65
6	25.00	9.2
7	29.40	11.56
8	31.3	12.90
9	32.3	13.60
Recycled HDPE	20.2	5.65

Note-LP-load at peak, PS- peak strength

Further analysis of this design has been done by Minitab software by taking Taguchi L9 and results have been obtained for SN ratio and mean. Analysis for peak strength, peak load has been done. Graphs for the same have also been obtained and shown in Fig. 2. Form Fig. 2, it has been observed that increase in temperature resulted into SN ratio up to a certain limit but then after increase in temperature resulted into increase in SN ratio. Further in case of RPM as well as proportions increase in value resulted into increase in SN ratio. After analysing graph Table 4 has been drawn from Minitab software itself for analysis of variance of SN ratio.

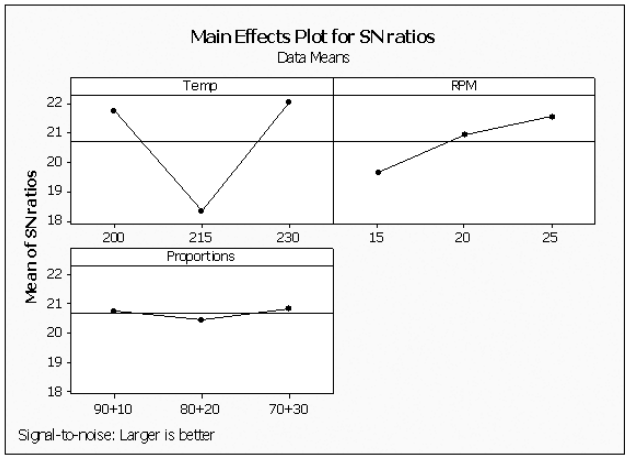

Figure 2: Main effects plot for SN ratio

From Table 4 it can be clearly seen that p value for temperature and RPM has came out to be less than 0.05. Hence these values are significant. There after Table 5 has been drawn as response for SN ratio.

Table 4
Analysis Of Variance For SN Ratio

Source	*DF*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*P*
A*	2	25.9246	25.924	12.96	351.89	0.003
B**	2	5.3763	5.3763	2.688	72.98	0.014
B^	2	0.2747	0.2747	0.137	3.73	0.211
	2	0.0737	0.0737	.036		
	8	31.6492				

NOTE * temperature, ** rpm, ^ proportions

Table 5
Response Table

Level	*TEMP*	*RPM*	*Proportions*
1	21.75	19.66	20.77
2	18.31	20.92	20.46
3	22.05	21.52	20.87
DELTA	3.74	1.85	0.41

Table 5 basically shows the contribution of individual component that has been taken in Taguchi optimization. In this, temperature has been given first rank on the basis of the contribution in properties of the final outcome. Similarly RPM and proportions are given 2nd and 3rd rank on the basis of contribution in properties respectively.

Similarly analysis of load at peak has also been studied and analysed. Fig. 3 shows the main effect plot for SN ratio for load at peak. From Fig. 3, it has been observed that as the temperature increases value of peak load increases. Same trend has been observed in case of RPM. However in case of proportions different trend was obtained as value of peak load first decreases and then increases. Further Table 6 has been drawn for analysis of variance for SN ratio for the same. Table 6 shows the P value obtained for each of the component in design of experiment. In case of the temperature and RPM P value obtained has value less or near to 0.05. It means these values are significant. In case of proportions P value is far away from 0.05, hence it is not significant value.

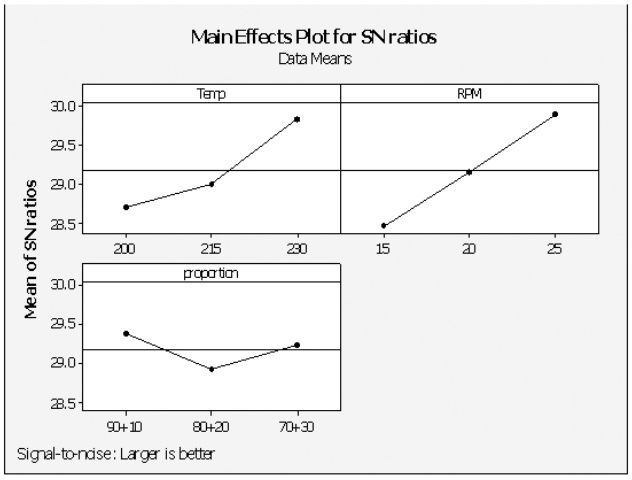

Figure 3: main effects plot for SN ratio

Table 6
Analysis Of Variance For SN Ratio

Source	*DF*	*Seq SS*	*Adj MS*	*F*	*P*
Temp	2	2.0262	1.01309	12.13	0.076
RPM	2	2.9851	1.49255	17.87	0.053
proportion	2	0.3119	0.15596	1.87	0.349
Residual Error	2	0.1671	0.08353		
Total	8	5.4902			

But percentage error in this experimentation came out to be less than 2.5 %. Hence it can be concluded as successful run of experiments. After this response Table 7 has been obtained for the same and shown.

Table 7
Response Table

Level	*Temp*	*RPM*	*Proportion*
1	28.70	28.47	29.37
2	29.00	29.16	28.92
3	29.82	29.88	29.23
Delta	1.12	1.41	0.45
Rank	2	1	3

Table 7 shows the response Table for various component of design of experiments. In this Table, temperature has been given 2nd rank as RPM and proportions have been given 1st and 3rd rank respectively. It means RPM has maximum contribution in property of product.

1. After the mechanical testing of the part DSC tests has been performed on the samples taken from the various proportions and discussed below. Basically this work is solely based on experimentation on the recycled material. So first of all DSC of recycled HDPE has been done to obtained various values regarding melting, enthalpy and decomposition of material. The structure of thermoplastic is affected by synthesis conditions as well as by processing conditions [11]. In Fig 4 shows the DSC graph for the recycled HDPE without reinforcement. This test was performed on three subsequent cycles i.e., heating, cooling and heating. The purpose of giving three subsequent cycles is that HDPE may have its manufacturing history. Along with this it may contain stresses that have to be removed. So that is why after first cycle of heating material has been given a cooling cycle and again heating Cycle was repeated to have optimum value of output parameters.

From Fig 4 it can be interpreted that in first cycle of heating, material experienced a sudden drop in curve and continuously goes downward and melting of material takes place in 7th minute after melting again a affect can be seen in curve in form of drop This may be due to the melting of pigment that was present in HDPE. It has been said earlier that material under investigation is recycled material it contains some sort of contamination and pigment (colour). That is why contamination and pigment shows their effect in DSC curve. After 19th minute and at temp of 230°c curve experiences a sudden hike. This hike in curve shows the decomposition of material. However HDPE starts decomposing at 400°c to 800°c [12]. The decomposition that has been discovered at 230°c may be because of contamination or due to pigment that has been added in HDPE during recycling. After study of the DSC data of the recycled HDPE without

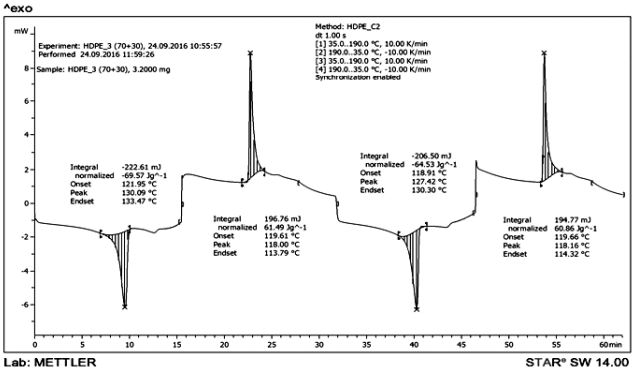

Figure 4: DSC curve for recycled HDPE

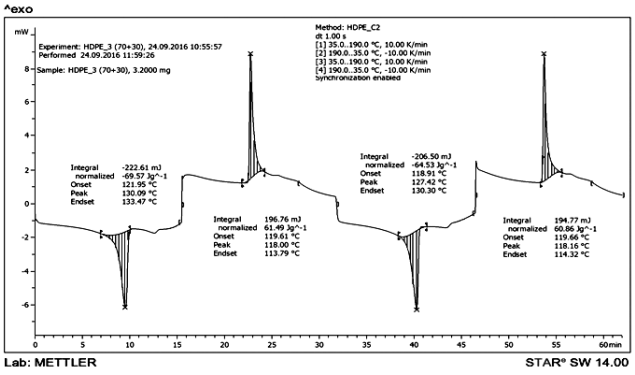

Figure 5: DSC curve for reinforced HDPE

reinforcement, DSC curve for reinforced HDPE has also been studied and shown in Fig. 5. In Fig. 5, DSC curve for the reinforced HDPE has been shown. In this it has been observed that melting of the material has occurred at 121.95°c. In case of recycled HDPE melting temperature was almost same as in case of reinforced HDPE i.e., 123°C. Again certain dips and hike occurred in curves. But in this four cycles were performed i.e., heating, cooling, heating and cooling. Curves obtained from both of the experiment were seems to be identical. This shows the adaptability of HDPE with reinforcements like SiC and Al_2O_3. After reinforcements of SiC and Al_2O_3 material again shows the same thermal properties in case of HDPE without reinforcements.

4. CONCLUSIONS

This paper highlights the effect of reinforcement on mechanical and thermal properties of recycled HDPE. It has been observed that various input parameter like temperature; RPM and proportions have Influence on the mechanical properties of reinforced HDPE. As observed in results obtained from analysis of variance for SN Ratio of peak loads and peak strength, p-value showed the significance of the result. On the other hand thermal properties of the HDPE with and without HDPE do not change much. This behaviour of HDPE shows the adaptability of HDPE with SiC and Al_20_3. After adding these filler HDPE shows nearly same melting and decomposition temperatures. It can be concluded from this research work that reinforced HDPE can be used for the thermal conditions but with the higher mechanical properties.

REFERENCES

[1] A. Aboulkas, K. El harfi, & A. El Bouadili, "Thermal degradation behaviors of polyethylene and polypropylene. Part I: Pyrolysis kinetics and mechanisms," Energy Conversation and Management, Vol. 51, 2010, pp. 1363–1369,.

[2] D.S. Achilias, A. Giannoulis, & G.Z. Papageorgiou, "Recycling of polymers from plastic packaging materials using the dissolution-reprecipitation technique," Polym. Bulletin, Vol. 63, 2009, pp. 449–465.

[3] K.B. Adhikary, S. Pang, & M.P. Staiger, "Dimensional stability and mechanical behaviour of wood-plastic composites based on recycled and virgin high-density polyethylene (HDPE)," Composite Part B Eng., Vol. 39, 2008, pp. 807–815.

[4] S.M. Al-Salem, P. Lettieri & J. Baeyens, "The valorization of plastic solid waste (PSW) by primary to quaternary routes: From re-use to energy and chemicals," Progress Energy Combustion Science, Vol. 36, 2010, pp. 103–129.

[5] S.M. Al-Salem, P. Lettieri, & J. Baeyens, "Recycling and recovery routes of plastic solid waste (PSW): A review," Waste Management, Vol. 29, 2009, pp. 2625–2643.

[6] M. Sanchez-Soto, A. Rossa, A.J. Sanchez, & J. Gamez-Perez, "Blends of HDPE wastes: Study of the properties," Waste Management, Vol. 28, , 2008, pp. 2565–2573.

[7] S. Yang, S. Bai, & Q. Wang, "Morphology, mechanical and thermal oxidative aging properties of HDPE composites reinforced by non-metals recycled from waste printed circuit boards," Waste Management, Vol. 57,2015, pp. 168-175.

[8] P. Herrera-Franco, A. Valadez-Gonzalez, & M. Cervantes-Uc, "Development and characterization of a HDPE-sand-natural fiber composite," Composite Part B Eng., Vol. 28, 1997, pp. 331–343.

[9] J. Navratil, M. Manas, A. Mizera, M. Bednarik, M. Stanek, & M. Danek, "Recycling of irradiated high-density polyethylene," Radiat. Phys. Chem., Vol. 106, 2015, pp. 68–72.

[10] R. Singh, N. Singh, F. Fabbrocino, F. Fraternali, & I.P.S. Ahuja, "Waste management by recycling of polymers with reinforcement of metal powder," Composite. Part B Eng., Vol. 105, 2016, pp. 23–29.

[11] A. Frick & A. Rochman, "Characterization of TPU-elastomers by thermal analysis (DSC)," Polymer Testing., Vol. 23, 2004,pp. 413–417.

[12] G. Vicente, J. Aguado, D. P. Serrano, & N. Sánchez, "HDPE chemical recycling promoted by phenol solvent," Journal of Analytical and applied Pyrolysis, Vol. 85, 2009, pp. 366–371.