Asian Journal of Water, Environment and Pollution, Vol. 20, No. 5 (2023), pp. 49-63.
DOI 10.3233/AJW230065

Experimental Study and Process Optimisation for Fabrication of Circular Sheet Made from Waste PP/HDPE via Extrusion and Hydraulic Press

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Received July 28, 2023; revised and accepted August 10, 2023

Abstract: Plastic waste is a well-known hazard to the ecosystem due to which many countries are exploring ways to mitigate this polymer from the environment. Various plastic wastes are generated after end use in the form of plastic bottles, plastic bags, bottle caps, straw, plastic cups, etc. These are generally made up of HDPE, LPDE, PP, PET, PS, etc. Therefore, this study focusses to utilise this wastage to make some value-added products. In this context, waste plastic bottles and containers made up of polypropylene and high-density polyethylene were targeted and shredded into small pieces ranging from 1.4 to 2 mm and mixed with additives in the extruder and hydraulic press to make circular sheets that can be used for electrical purposes. During the study, the effect of various process parameters on fabricated circular sheet properties such as tensile strength, melt flow index (MFI), and thermal conductivity were investigated. The developed non-linear theoretical models were found to be in good agreement with the experimental data. The gradient descent method is applied in BBD for estimating the optimum condition for fabricating a circular sheet. Under optimum conditions, the tensile strength and thermal conductivity were found to be 1535 MPa and 0.0312 W/mK, respectively, for the HDPE circular sheet using extrusion. The tensile strength, MFI, and thermal conductivity were determined using a Universal testing machine, melt flow tester (ASTM D1238), and Thermal constant analyser based on ASTM D1350.

Key words: Polypropylene, HDPE, marble slurry, HPMC, melt flow index, thermal conductivity.

Introduction

Several countries are in a developing phase and are facing natural resource shortages. Many sustainable options are being developed to enhance the growth of a country without putting stress on natural resources. Recycling of plastic waste is one of the many solutions where scientists and researchers are making efforts. The plastic waste is being non-biodegradable nature is suggested to be a perfect choice as a raw material for recycling. Major sources of plastic material are packaging films, wrapping materials, shopping and garbage bags, fluid containers, etc. It has been noticed that plastic waste generation has grown to 400 million tonnes in 2019 (Devasahayam et al., 2019). Plastic packaging has been reported as an essential consumable entity used across the globe (Achilias et al., 2009).

The synergism of the polymers and additives was studied at various parameters including processing temperature, polymer structure, and mixing ratios (Liu et al., 2015; Rao et al., 2019; Şimşek and Uygunoğlu, 2016; Singh et al., 2017, 2016; Sutar et al., 2018; Turku et al., 2017). Ugur (2017) reported that recycled polypropylene granules undergoing the

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compounding extrusion process get converted into useful reinforcement polymer composite with better mechanical and thermal properties (Soy et al., 2017). It has been found that 40% mixing of polymer in fibre results in better product quality in terms of strength and thermal stability (Saba et al., 2015).

In this study, wastes of HDPE and PP were taken as raw materials for the development of electrical circuit breaker plates using sustainable approaches by extrusion and hydraulic press method. The effect of various process parameters of both techniques was understood using a Box-Behnken design with a target of high tensile strength and melt flow index with low thermal conductivity of the prepared electrical circuit breaker.

Materials and Experimental Methods

Materials

The chemicals such as HPMC (Sigma-Aldrich and LR grade) and calcium carbonate (Avarice and LR grade) were purchased from *ASES Chemical Works* Jodhpur, India and Sita Chemical Pvt Ltd, India.

Experimental Procedure for Extrusion for Sheet Fabrication

The waste plastic bottles of PP and HDPE were washed and shredded to different grain sizes. Thereafter, these shreds were mixed under different compositions with HPMC and calcium carbonate as additives. The mixed material is fed into the extruder via a hopper comprising heaters along the barrel. The feed mixture is allowed to move forward by rotating the screw speed (rpm ranges from 65 to 85 m^{-1} and L/D ratio of 20:1). The breaker plate is attached at the exit of extrudate in order to convert the helical motion of the extrudate into the linear profile. The extrudate emerging from the die $(\phi_d = 2\text{ mm})$ is directly sent into the hydraulically attached mould system of the circular plate $(\phi_p = 9.8\text{ cm})$ and gets filled in 2 minutes. The filled mould is allowed to cool at room temperature for 5 second. The in-house fabricated extrusion setup is shown in Figure 1. The range of process parameters under which the extrusion is conducted is shown in Table 1.

Sheet Casting Using Hydraulic Ram

The recycled HDPE and PP after converting into scraps (grain size: 1.4 to 2.0 mm) were placed in the die with additives and filler. The die was allowed to heat to a temperature range of 100-200°C for 15 minutes. Once the scraps were softened by the action of heating, the die was hydraulically pressed under the pressure ranges from 120 to 170 psi. The dimension of the die is taken for sheet fabrication as thickness (δ) and diameter (ϕ_p) as 2 mm, and 9.8 cm, respectively. After 15 minutes

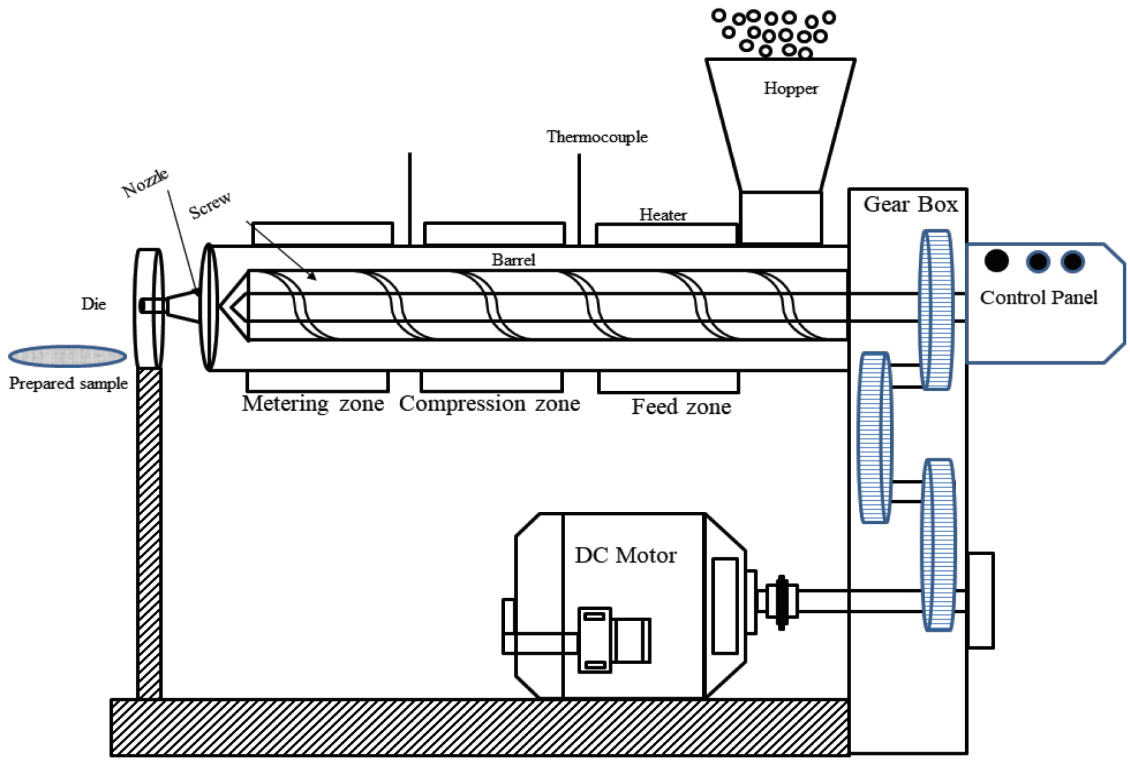


Figure 1: Extrusion process line diagram.

Table 1: Process parameters range of both process for extrusion and sheet casting

	Extrusion process		*Sheet casting process*	
S. No	*Process parameter for extrusion*	*Value/Range*	*Process parameter for sheet casting*	*Value/Range*
1.	Temperature (°C)	100 – 120	Temperature (°C)	100 – 200
2.	RPM	65-85 min^{-1}	Additives concentration (by weight %)	0%-20%
3.	Additives concentration (by weight %)	0%-20%	Pressure (psi)	170-120
4.	BSS Grain Size	12-8 or (2.0 mm-1.40 mm)	BSS Grain Size	12-8 or (2.0 mm-1.40 mm)

of hydraulic pressing and heating, the sample is taken out from the machine and placed immediately into the water bath for solidification and dimensional stability. Finally, the fabricated circular sheet characteristics such as tensile strength, melt flow index, and thermal conductivity were estimated using standard methods.

Design of Experiment

In this work, the DOE array was created using the Box-Behnken design and the variables were coded as ±1 (–1 for lowest and +1 for highest), and zero (0) for centre points. Response surface methodology comprising 4 factors, 3 responses and 2 blocks were taken for 29 experimental runs. The experiments were conducted as per the developed design. The responses in terms of tensile strength, melt flow index and thermal conductivity of recycled HDPE/PP were measured for all 29 runs as shown in Tables 2 and 3 for extrusion and hydraulic press method.

Results and Discussion

Non Linear Regression and ANOVA

The non-linear regression model for tensile strength, melt flow index and thermal conductivity were fitted from DOE data using BBD design (Tables 2 and 3). The fitting is done using nonlinear regression technique by minimisation of the sum of square errors. The model was fitted as per Equation 1.

$$Y = b_0 + b_1 \times A + b_2 \times B + b_3 \times C + b_4 \times D + b_{11} \times A^2 + b_{22} \times B^2 + b_{33} \times C^2 + b_{44} \times D^2 + b_{12} \times AB + b_{13} \times AC + b_{14} \times AD + b_{23} \times BC + b_{24} * BD + b_{34} * CD \quad (1)$$

The operating variables such as temperature, screw speed, grain size and additive concentration are represented by A, B, C, and D, respectively for the extrusion process whereas the operating variable namely press temperature, hydraulic pressure, grain size, and additive concentration are illustrated by α, β, γ, and ϕ, respectively, for sheet casting press process. The regression equations of responses as a function of independent experimental variables are shown by Equations 2 to 13 for coded units as follows:

Extrusion Process for HDPE

Tensile strength (TS) $= 1731.80 + 136.17A - 7.75B + 136.83C - 129.08D - 33.77A^2 - 104.65B^2 - 45.78C^2 - 494.65D^2 + 10.25AB + 70.75AC + 37.50AD + 78.50BC - 30.50BD + 8.75CD$ (2)

Melt flow index (MFI) $= 3.55 + 0.434 - 0.23\ B + 0.39\ C - 0.86\ D - 0.35A^2 - 0.12B^2 - 0.39\ C^2 - 0.073\ D^2 + 0.25\ AB - 0.029AC + 0.12\ A\ D - 0.068\ BC + 0.19BD - 0.25CD$ (3)

Thermal Conductivity (TC) $= 0.51 + 0.254 - 0.032B - 0.013\ C - 0.057\ D - 0.23\ A^2 + 4.112E - 003\ B^2 + 0.019\ C^2 + 0.026\ D^2 - 8.255E - 003AB + 0.0164C - 0.0434B + 0.036BC - 0.042BD + 0.019CB$ (4)

Extrusion Process for PP

Tensile strength (TS) = 1311.60 + 134.75A – 18.08B + 70.75C – 91.08D + 5.12 A2 – 19.38B2 – 24.63C2 - 425.88D2 + 73.00AB - 4.75AC + 23.75BC -0.50BD +16.75CD (5)

Melt flow index (MFI) = 4.15 + 0.354 – 0.19*B* + 0.36C – 0.99D – 0.38A2 – 0.14B2 – 0.38C2 – 0.13D2 + 0.32AB + 0.0154C – 0.0974 D + 0.049BC + 2.300E – 003BD – 0.29CD (6)

Thermal Conductivity (TC) $= 0.35 + 0.164 - 0.016\ B - 5.539E - 003\ C - 0.061\ D - 0.15\ A^2 - 6.939E - 003\ B^2 - 0.013\ C^2 - 0.044\ D^2 - 0.0124\ B + 0.010\ AC - 0.054\ A\ D - 0.027\ BC - 0.041\ BD + 3.650E - 003CD$ (7)

Table 2: Design matrix for three factors and responses for recycled HDPE/PP using extrusion

Factor 1 *A:Temp*	*Factor 2* *B:RPM*	*Factor 3* *C:Grain*	*Factor 4* *D:Additive*	*Response 1* *TS (HDPE)*	*Response 2* *TS (PP)*	*Response 3* *MFI (HDPE)*	*Response 4* *MFI (PP)*	*Response 5* *TC (HDPE)*	*Response 6* *TC (PP)*
110.00	75.00	10.00	10.00	1739	1323	3.4792	4.1052	0.5594	0.3974
100.00	75.00	8.00	10.00	1547	1146	2.0071	2.9417	0.05847	0.03209
100.00	75.00	10.00	0.00	1284	894	3.9507	4.0807	0.03782	0.02958
110.00	85.00	12.00	10.00	1690	1286	3.0721	3.5107	0.4991	0.2678
120.00	65.00	10.00	10.00	1805	1453	3.4816	3.7211	0.5093	0.3752
120.00	75.00	10.00	0.00	1277	967	4.3116	4.8352	0.6788	0.4287
110.00	85.00	10.00	0.00	1361	979	3.5061	4.9076	0.5811	0.3983
110.00	75.00	10.00	10.00	1726	1316	3.5209	4.1742	0.4096	0.3592
100.00	75.00	10.00	20.00	987	698	1.8693	2.6031	0.04889	0.03082
120.00	85.00	10.00	10.00	1912	1635	3.6911	4.1007	0.4698	0.3189
110.00	75.00	8.00	20.00	891	683	1.6527	2.0041	0.4329	0.2056
110.00	65.00	8.00	10.00	1562	1243	3.0507	3.8039	0.6714	0.3713
110.00	75.00	10.00	10.00	1706	1296	3.5976	4.2076	0.5318	0.3125
110.00	65.00	10.00	20.00	1019	793	2.6759	3.021	0.6023	0.2912
100.00	75.00	12.00	10.00	1579	1282	2.4821	3.125	0.06253	0.02592
120.00	75.00	12.00	10.00	1953	1467	3.4031	4.0207	0.5895	0.3798
120.00	75.00	10.00	20.00	1130	897	2.7146	2.9681	0.5171	0.2156
110.00	75.00	12.00	20.00	1251	832	2.4701	2.7931	0.4578	0.2007
110.00	75.00	10.00	10.00	1739	1323	3.4792	4.1052	0.5594	0.3974
110.00	65.00	12.00	10.00	1710	1378	3.8201	4.261	0.4968	0.3901
110.00	85.00	8.00	10.00	1228	1056	2.5728	2.8592	0.5298	0.3578
100.00	65.00	10.00	10.00	1309	1121	2.9601	3.6819	0.04873	0.02807
110.00	65.00	10.00	0.00	1256	983	4.3218	4.9376	0.5967	0.3105
110.00	75.00	8.00	0.00	1163	939	3.2017	3.7935	0.6589	0.3698
110.00	75.00	10.00	10.00	1749	1300	3.6597	4.1506	0.5072	0.2997
110.00	85.00	10.00	20.00	1002	787	2.6018	3.0002	0.4193	0.2139
110.00	75.00	12.00	0.00	1488	1021	5.0047	5.7439	0.6094	0.3503
120.00	75.00	8.00	10.00	1638	1350	3.0421	3.7759	0.5206	0.3445
100.00	85.00	10.00	10.00	1375	1011	2.1641	2.7941	0.04225	0.01981

Table 3: Design matrix for three factors and responses for recycled HDPE/PP using hydraulic press method

Factor 1	*Factor 2*	*Factor 3*	*Factor 4*	*Response 1*	*Response 2*	*Response 3*	*Response 4*	*Response 5*	*Response 6*
A: Temp.	*B:pressure*	*C:Grain*	*D:Additive*	*T S (HDPE)*	*T S (PP)*	*MFI (HDPE)*	*MFI (PP)*	*TC (HDPE)*	*TC (PP)*
150.00	145.00	8.00	80.00	894	865	2.4922	3.0141	0.4341	0.3341
200.00	120.00	10.00	90.00	1020	968	2.7071	3.0397	0.5018	0.3208
150.00	120.00	10.00	100.00	1206	1131	3.7869	4.3802	0.5015	0.4795
150.00	170.00	8.00	90.00	924	782	2.3936	3.8076	0.4923	0.4003
100.00	120.00	10.00	90.00	402	372	0.7802	0.9041	0.0152	0.0317
200.00	170.00	10.00	90.00	1164	930	2.9892	3.7103	0.5271	0.4927
200.00	145.00	8.00	90.00	995	734.5	2.7862	3.9246	0.4639	0.3619
150.00	145.00	10.00	90.00	862	715	1.3107	2.315	0.3847	0.2808
150.00	145.00	10.00	90.00	862	715	1.3107	2.315	0.3847	0.2808
150.00	145.00	12.00	100.00	1478	1289	3.8489	4.2621	0.5822	0.4621
150.00	120.00	12.00	90.00	898	823	1.2652	2.6794	0.3989	0.3212
200.00	145.00	10.00	100.00	1570	1176	4.9748	5.0842	0.4985	0.4023
150.00	145.00	8.00	100.00	1292	1071	3.1737	4.7801	0.4034	0.3728
150.00	170.00	10.00	100.00	1458	1332	3.8552	4.7021	0.4584	0.3872
100.00	145.00	10.00	80.00	400	362	0.5402	0.7231	0.0851	0.0106
200.00	145.00	10.00	80.00	902	672	1.0404	2.1242	0.5201	0.4135
150.00	145.00	12.00	80.00	932	783	1.1585	2.5023	0.3982	0.2894
100.00	145.00	10.00	100.00	411	392	0.8205	1.0211	0.0189	0.01236
150.00	145.00	10.00	90.00	862	715	1.3107	2.315	0.3847	0.2808
200.00	145.00	12.00	90.00	1027	937	2.1743	3.9901	0.4769	0.3785
150.00	120.00	10.00	80.00	890	698	1.4509	1.7592	0.3509	0.2746
100.00	145.00	12.00	90.00	397.48	389	0.6904	0.9274	0.0821	0.0189
100.00	145.00	8.00	90.00	405	398	0.7506	0.8963	0.0157	0.01011
150.00	170.00	10.00	80.00	922	858	1.7356	2.5209	0.4091	0.3146
150.00	145.00	10.00	90.00	862	715	1.3107	2.315	0.3847	0.2808
100.00	170.00	10.00	90.00	418	385	0.6158	0.8264	0.0443	0.1072
150.00	170.00	12.00	90.00	947	872	2.7759	4.2597	0.4713	0.3524
150.00	120.00	8.00	90.00	882	695	3.3361	4.0108	0.4474	0.3902
150.00	145.00	10.00	90.00	862	715	1.3107	2.315	0.3847	0.2808

Sheet Casting Process for HDPE

Tensile strength (TS) $= 862.00 + 353.71\alpha + 44.58\beta + 23.96\gamma + 206.25\phi - 201.83\alpha^2 + 50.61\beta^2 + 43.16\gamma^2 + 203.60\phi^2 + 32.00\alpha\beta + 9.88\alpha\gamma + 164.25\alpha\phi + 1.75\beta\gamma + 55.00\beta\phi + 37.00\gamma\phi$ (8)

Melt flow index (MFI) $= 1.31 + 1.04\alpha + 0.087\beta - 0.25\gamma + 1.00\phi - 0.22\alpha^2 + 0.63\beta^2 + 0.53\gamma^2 + 0.78\phi^2 + 0.11\alpha\beta - 0.14\alpha\gamma + 0.91\alpha\phi + 0.61\beta\gamma - 0.054\beta\phi + 0.50\gamma\phi$ (9)

Thermal conductivity (TC) $= 0.38 + 0.23\alpha + 0.016\beta + 0.013\gamma + 0.022\phi - 0.14\alpha^2 + 0.027\beta^2 + 0.033\gamma^2 + 0.032\phi^2 - 9.500E - 004\alpha\beta - 0.013\alpha\gamma + 0.011\alpha\phi + 6.875E - 003\beta\gamma - 0.025\beta\phi + 0.054\gamma\phi$ (10)

Sheet Casting Process for PP

Tensile Strenth(TS) $= + 715.00 + 259.96\alpha + 39.33\beta + 45.63\gamma + 179.42\phi - 181.17\alpha^2 + 85.15\beta^2 + 59.21\gamma^2 + 183.602\phi^2 - 12.75\alpha\beta + 52.87\alpha\gamma + 118.57\alpha\phi - 9.50\beta\gamma + 10.25\beta\phi + 75.0\gamma\phi$ (11)

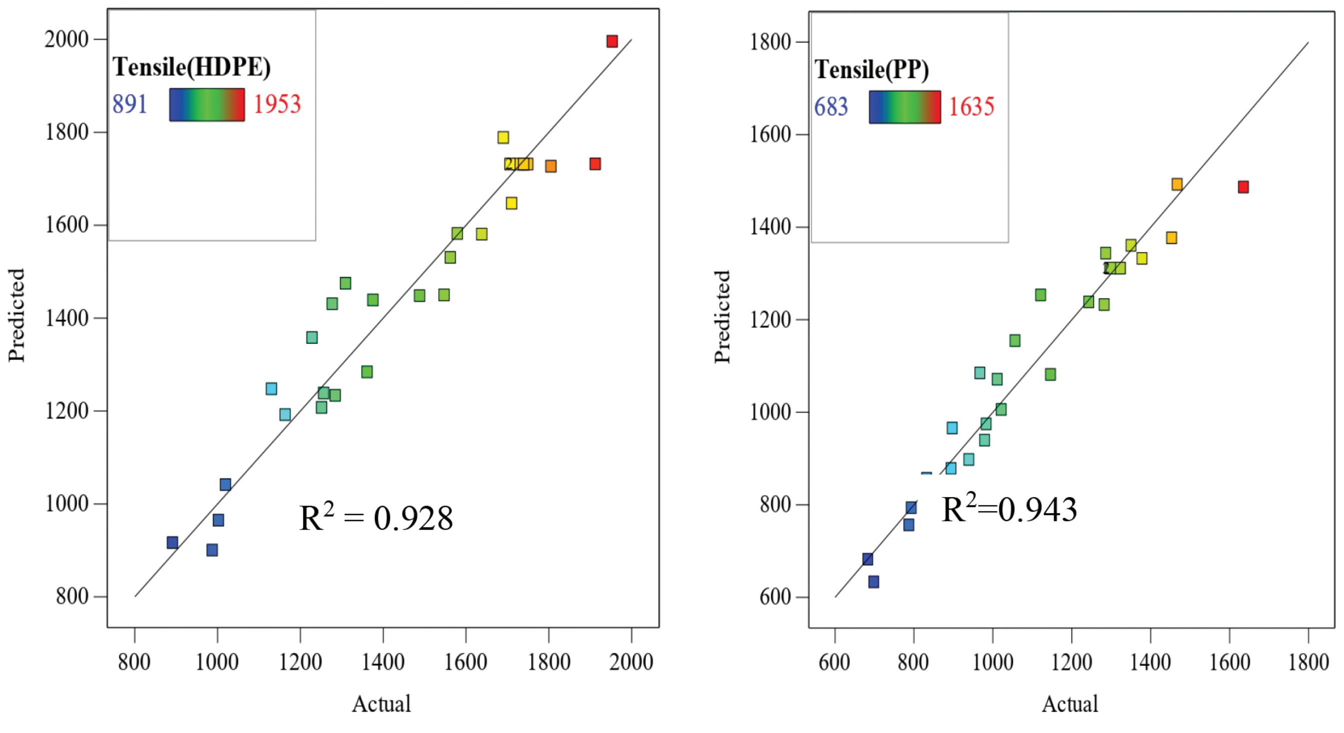
Melt flow index (MFI) $= + 2.32 + 1.38\alpha + 0.25\beta - 0.15\gamma + 0.97\phi - 0.67\alpha^2 + 0.51\beta^2 + 0.81\gamma^2 + 0.54\phi^2 + 0.19\alpha\beta + 8.600E - 003\alpha\gamma + 0.67\alpha\phi + 0.45\beta\gamma - 0.11\beta\phi - 1.550E - 003\gamma\phi$ (12)

Thermal conductivity (TC) $= + 0.28 + 0.18\alpha + 0.020\beta - 3.909E - 003\gamma + 0.040\phi - 0.11\alpha^2 + 0.055\beta^2 + 0.032\gamma^2 + 0.040\phi^2 + 0.024\alpha\beta + 1.952E - 003\alpha\gamma - 3.240E - 003\alpha\phi + 5.275E - 0030\beta\gamma - 0.033\beta\phi + 0.034\gamma\phi$ (13)

The developed theoretical model of each response for both processes is found in well agreement with the experimental data as shown in Figures 2 to 7 since the R^2 value ranges between 0.920 and 0.984.

ANOVA is applied to determine the significant parameters for responses. It is found that barrel average temperature and grain size affect synergistic significantly on the tensile strength of fabricated circular disk made from recycled HDPE and PP by extrusion process. However, additive concentration affects significantly in an antagonistic manner. The barrel temperature is high enough to melt recycled polymer scrap of different grain sizes which in turn is uniformly mixed with additives. Moreover, the screw to barrel diameter ratio is approximately one which creates extreme stress and aids the mixing phenomena as a result tensile strength increases.

The ANOVA analysis for MFI and thermal conductivity were conducted and it was observed that average barrel temperature (A), and additive concentration (D) have



(a) (b)

Figure 2: Predicted tensile strength (MPa) versus actual tensile strength (MPa) for (a) HDPE, and (b) PP using extrusion.

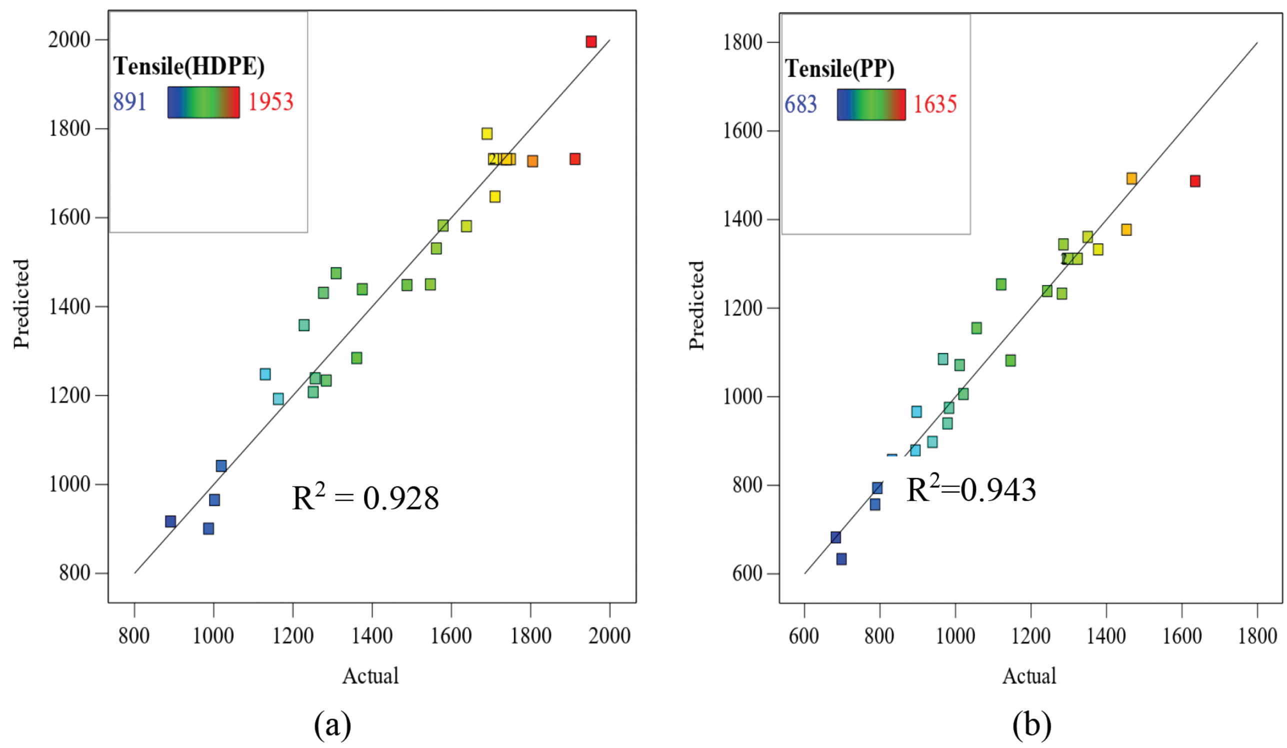


Figure 3: Predicted MFI (g/10 minute) versus actual MFI (g/10 minute) for (a) HDPE, and (b) PP using extrusion.

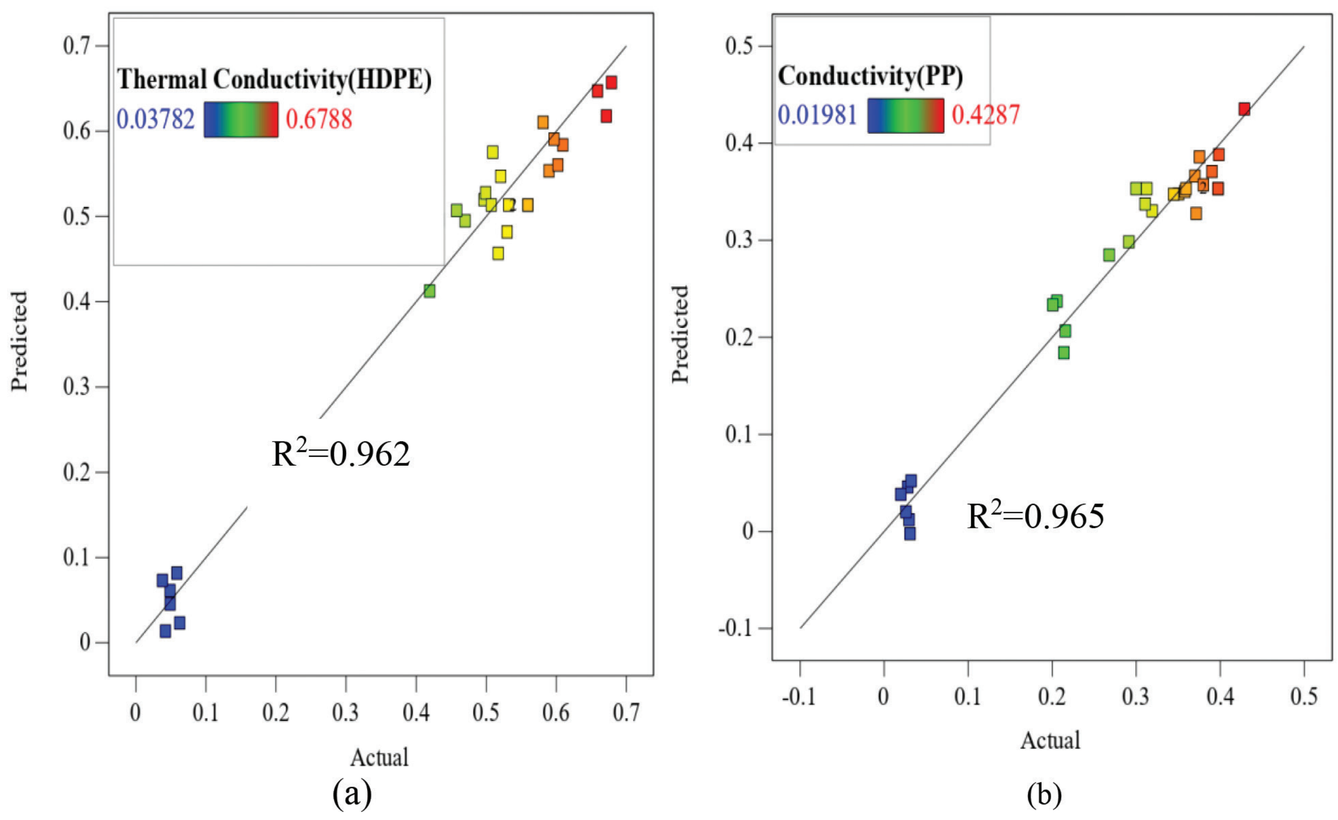
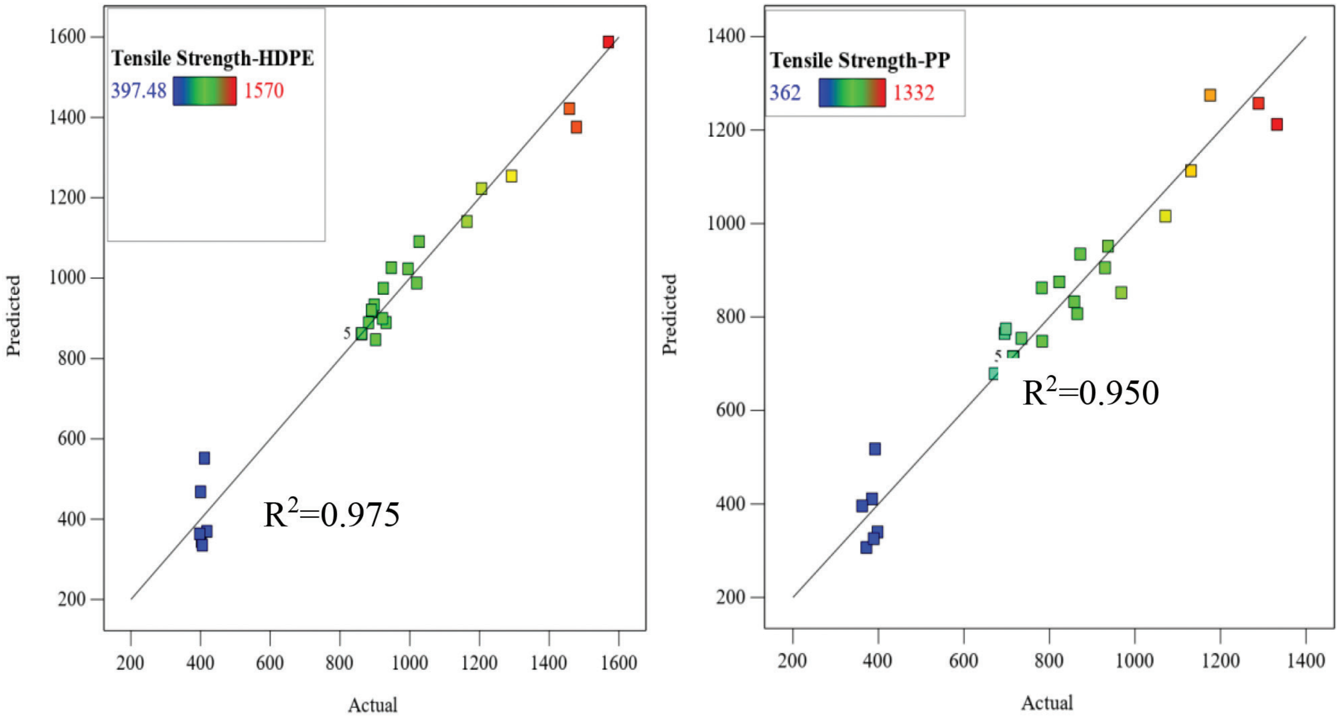
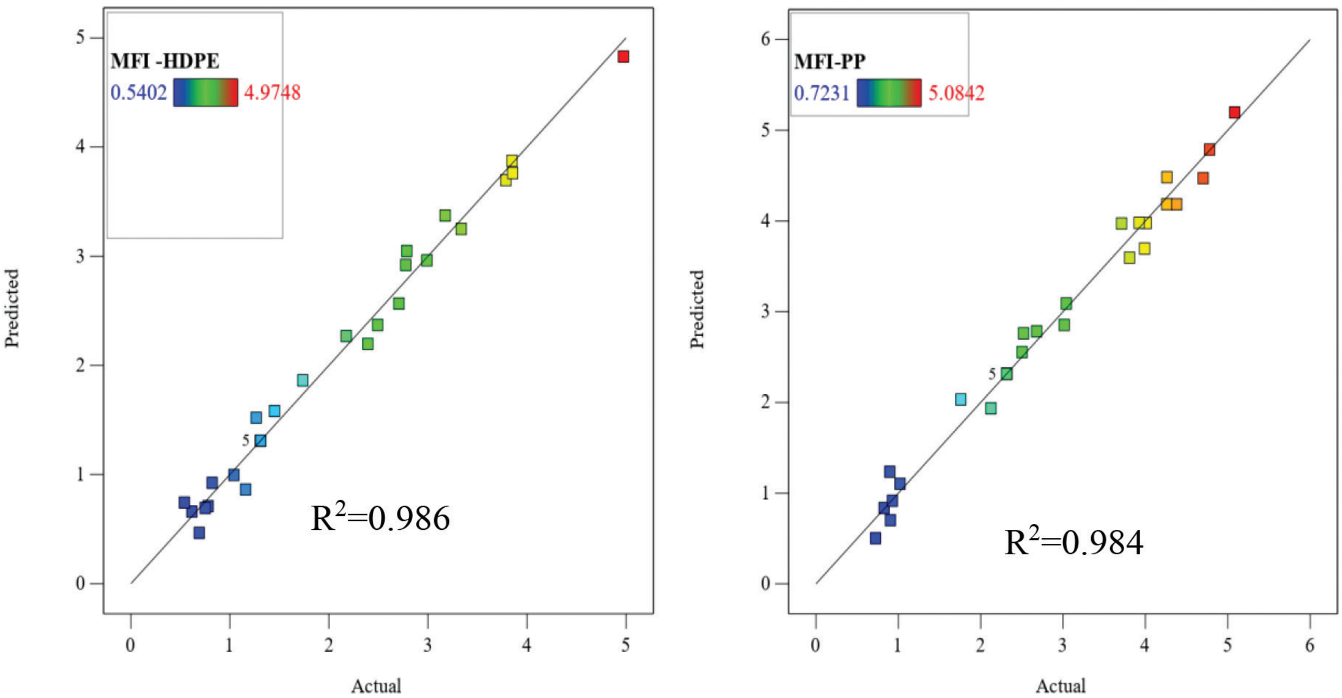


Figure 4: Predicted thermal conductivity (W/m. K) versus actual thermal conductivity (W/m. K) for (a) HDPE and (b) PP using extrusion.



(a) (b)

Figure 5: Predicted tensile strength (MPa) versus actual tensile strength (MPa) for (a) HDPE, and (b) PP using hydraulic press.



(a) (b)

Figure 6: Predicted MFI (g/10 minute) versus actual MFI (g/10 minute) for (a) HDPE, and (b) PP using casting process.

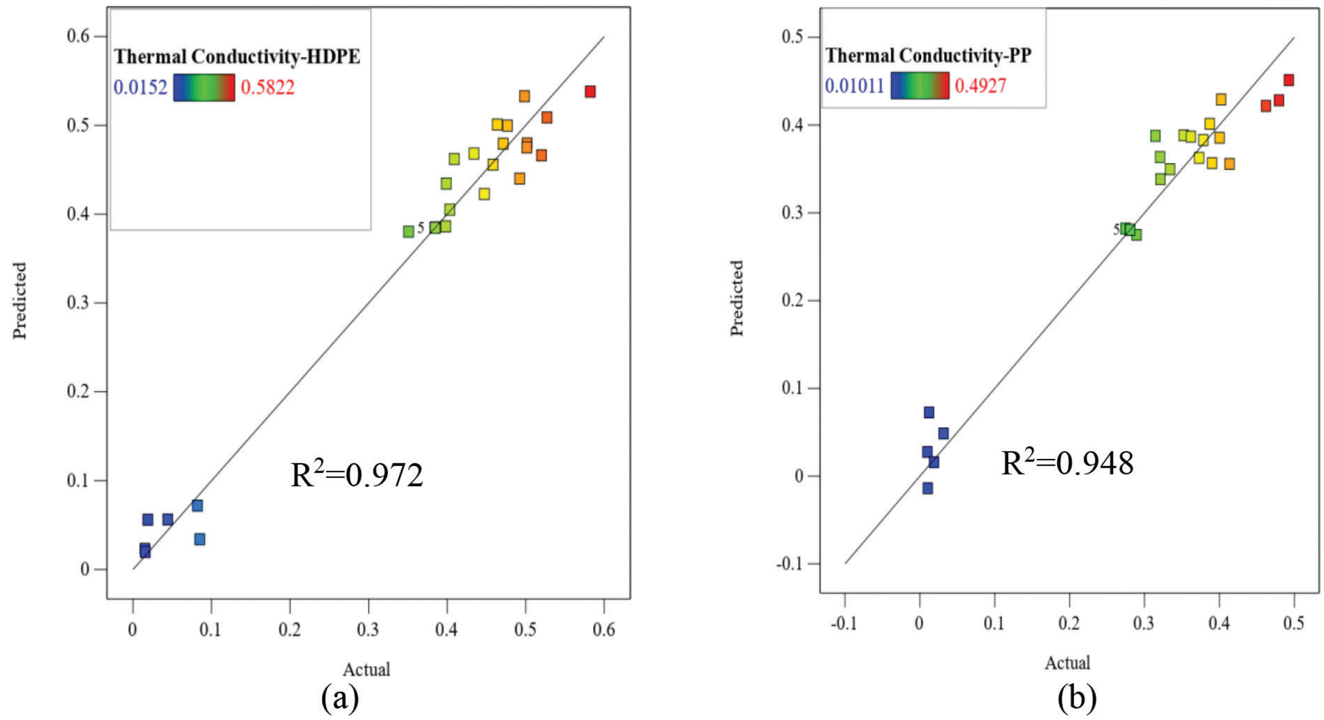


Figure 7: Predicted thermal conductivity (W/m. K) versus actual thermal conductivity (W/m. K) for (a) HDPE and (b) PP using casting process.

significant effect on MFI and thermal conductivity. The former is synergistic whereas the latter contributes antagonistically to the responses. It was also evident from the ANOVA study that grain size (*C*) affects MFI significantly however it has insignificant behaviour on thermal conductivity. Thermal conductivity is the intrinsic property that is independent of the dimensions/mass/etc of the body. Therefore, grain size (*C*) does not contribute to the thermal conductivity. Similarly, ANOVA was applied during the fabrication of circular disk using recycled HDPE as well as PP by hydraulic press sheet casting process. It was found that moulding press temperature (α), hydraulic gage pressure (β), and additive concentration (ϕ) had significant synergistic effects on the tensile strength of fabricated circular disk.

The significant contributory factor for MFI was found to be moulding press temperature (α) and, additive concentration (ϕ). These factors resembled a synergistic effect on MFI however, another contributory factor grain size (γ) had an antagonistic effect on MFI. The probable reason is that on increasing the moulding temperature, the viscosity of the polymer melt decreases as per the Arrhenius equation depicted in Equation 14:

$$\eta = k_1 e^{\frac{E_0}{RT}} \tag{14}$$

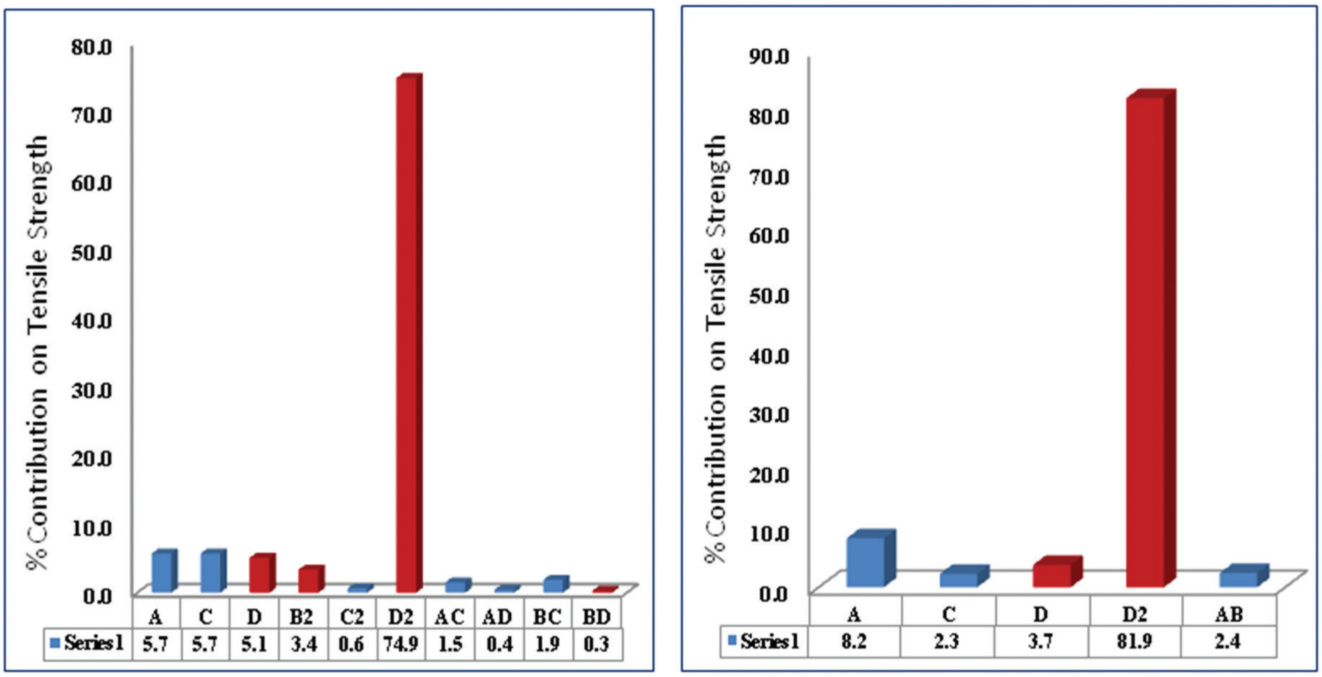
where η is the viscosity of the polymer melt, k_1 is the constant, E_0 stands for activation energy, R is the gas constant and T is the moulding temperature. As a result, the MFI gets increased under fixed load conditions which can be understood by the relation as follows:

$$MFI = \frac{4.98 \times 10^4 \ \rho L}{\eta} \tag{15}$$

The ANOVA was also conducted for thermal conductivity and it was found that the significant contributory parameter was α among all the individual parameters whereas for binary interaction the major contributory parameters were found to be α^2, γ^2, and ϕ^2.

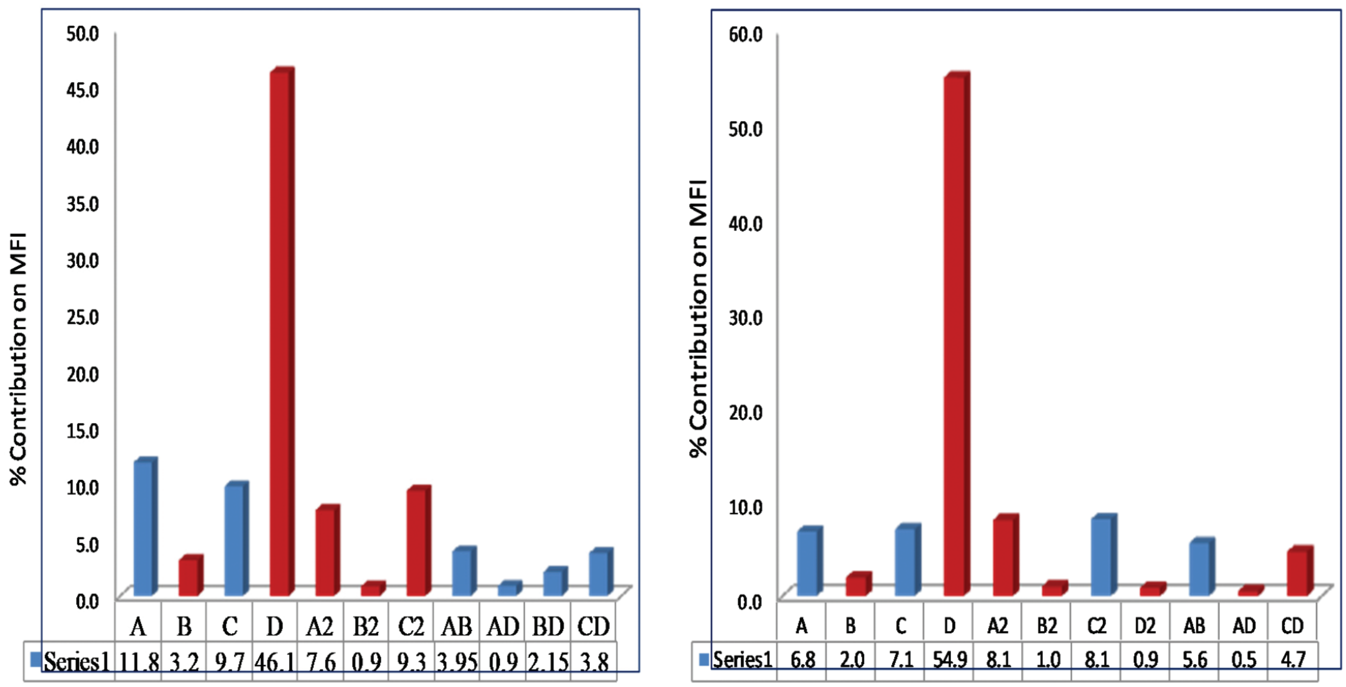
The percentage contribution of all the significant parameters is shown in Figures 8-11 for Tensile strength, MFI, and thermal conductivity for sheets fabricated using an extrusion process. Whereas, for the hydraulic press process, it is depicted in Figures 12 to 15. The SEM image of fabricated HDPE circular sheet using extrusion and hydraulic press are shown in Figures 10 and 14, respectively.

The percentage contribution of all the significant parameters such as tensile strength, MFI and thermal conductivity for fabricated circular sheets using the extrusion process are discussed thoroughly in this study. It is observed from Figure 8 that the positive



(a) (b)

Figure 8: Percentage contribution on tensile strength for extrusion process (a) HDPE and (b) PP.



(a) (b)

Figure 9: Percentage contribution on melt flow index for extrusion process (a) HDPE and (b) PP.

contribution of average barrel temperature (*A*) on the tensile strength of sheets fabricated from HDPE and PP was found to be 5.7% and 8.2%, respectively, whereas the maximum contribution on tensile strength was observed by the binary interaction D^2 of value 81.9% for PP sheet. On the other hand, the antagonistic behaviour of the additive concentration (*D*) may be attributed 3.7% on tensile strength. The probable reason for the antagonistic relation with tensile strength may be understood as loading of $CaCO_3$ may generate residual

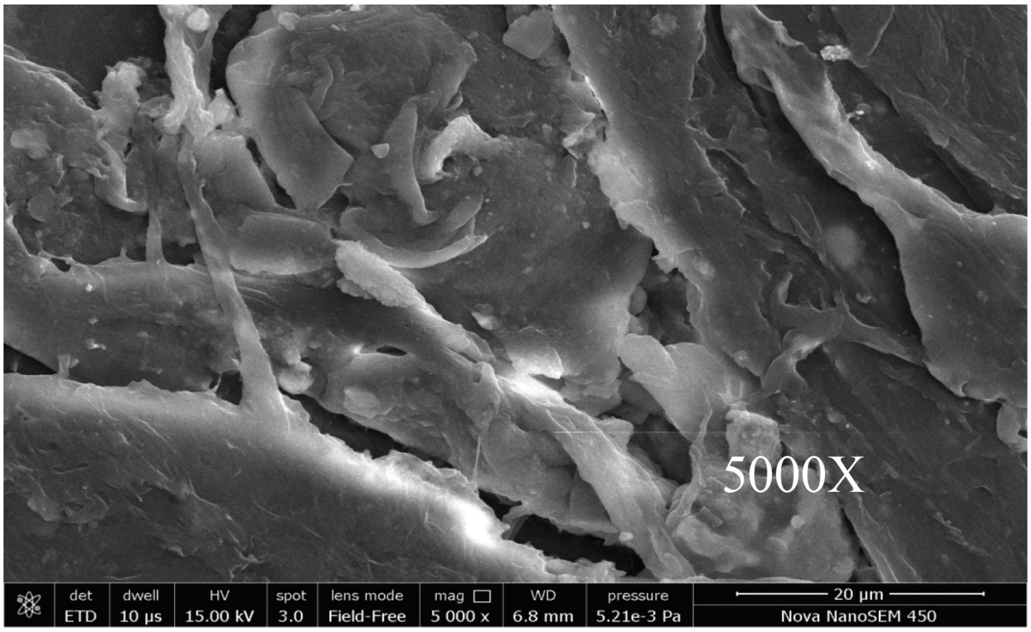
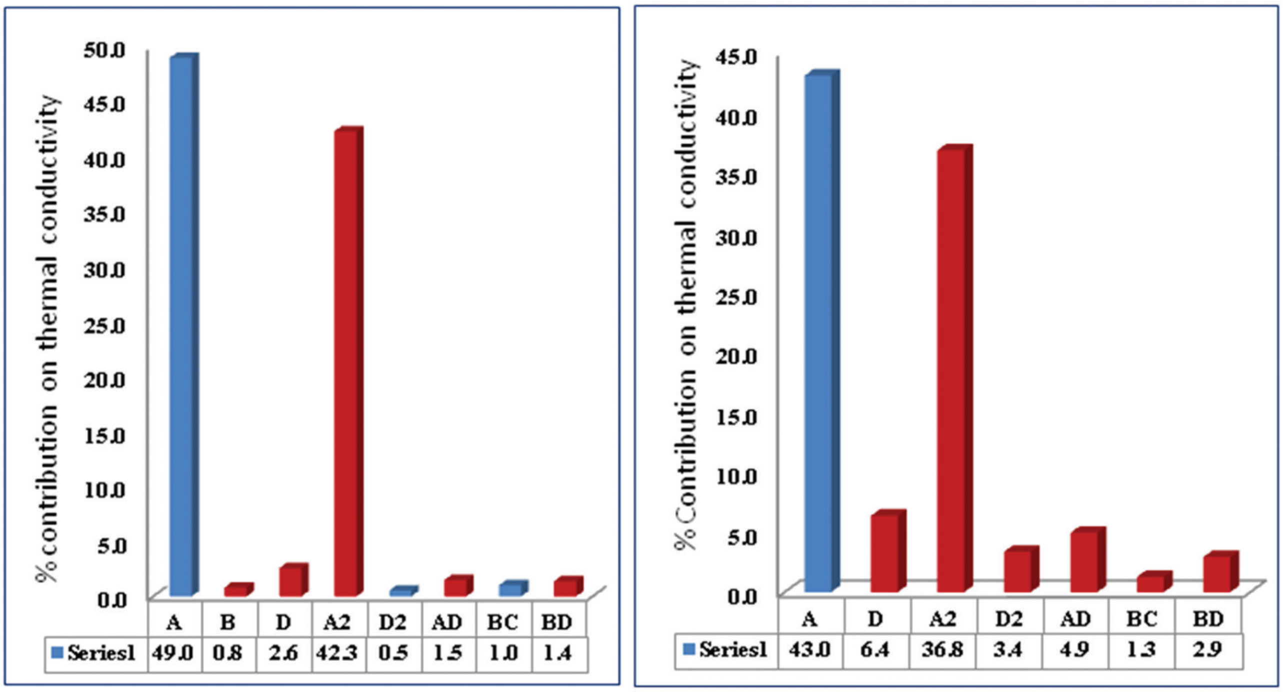
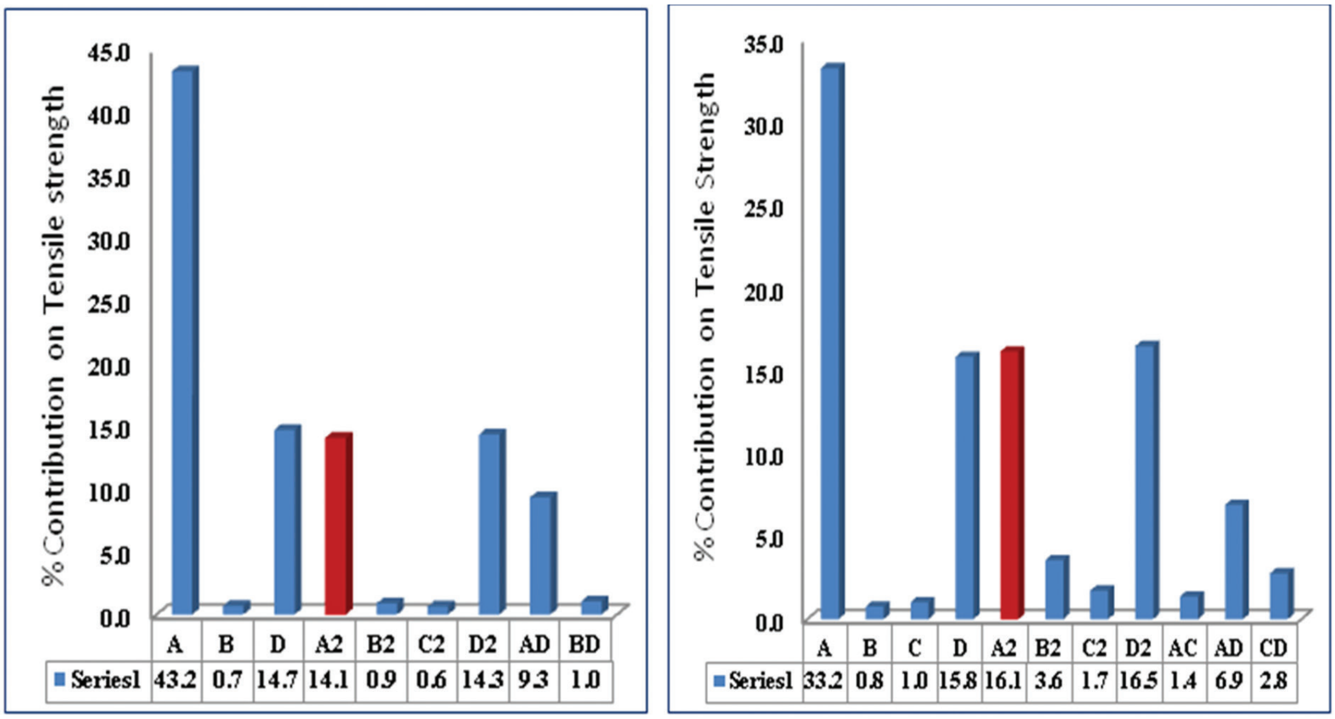


Figure 10: SEM image of HDPE circular sheet fabricated using extrusion.



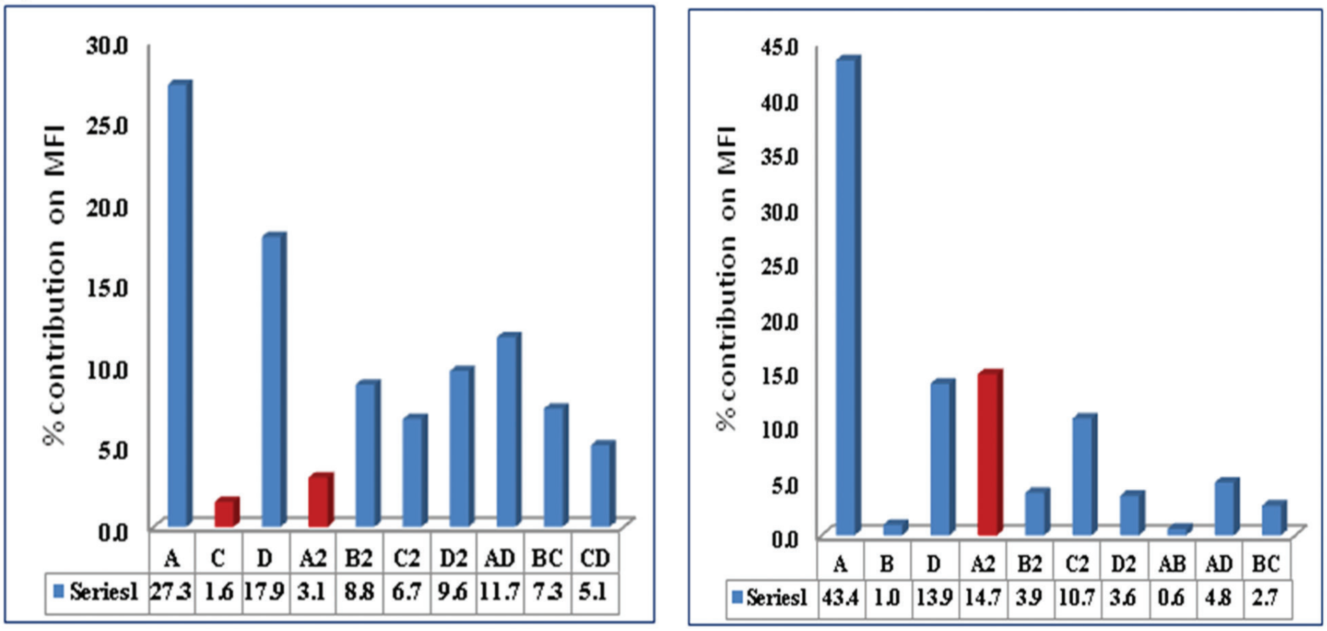
(a) (b)

Figure 11: Percentage contribution on thermal conductivity for extrusion process (a) HDPE and (b) PP.



(a) (b)

Figure 12: Percentage contribution on tensile strength for casting process (a) HDPE and (b) PP.



(a) (b)

Figure 13: Percentage contribution on Melt flow index for casting process (a) HDPE and (b) PP.

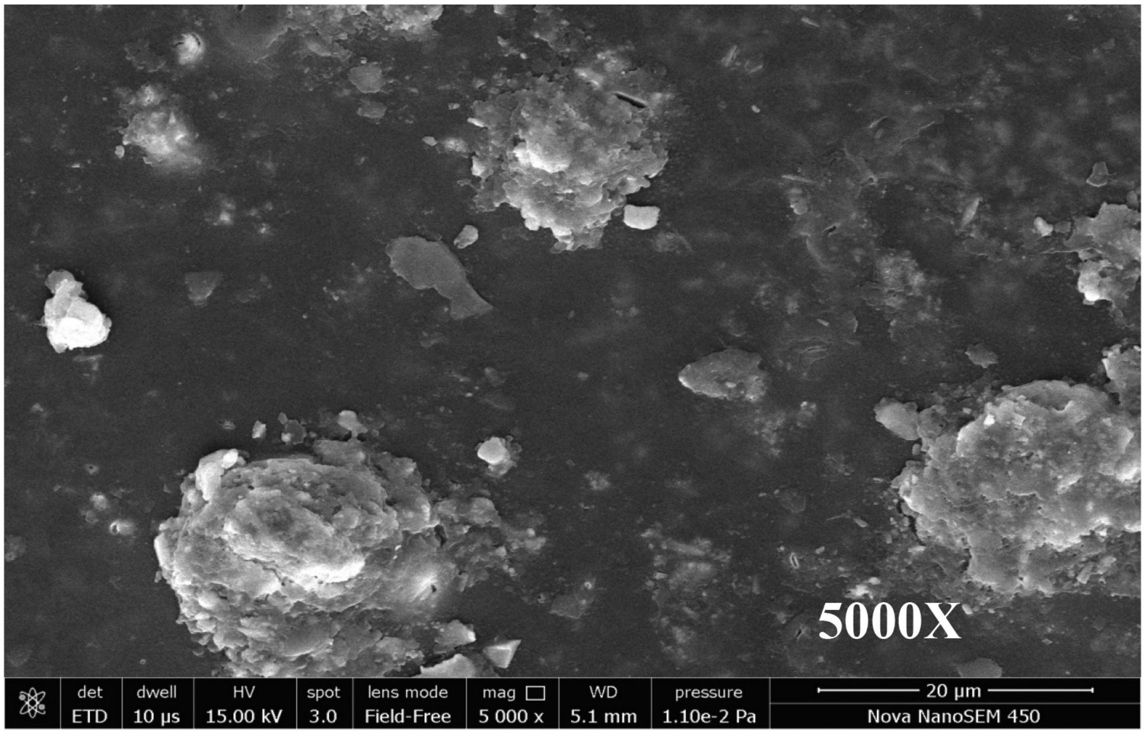
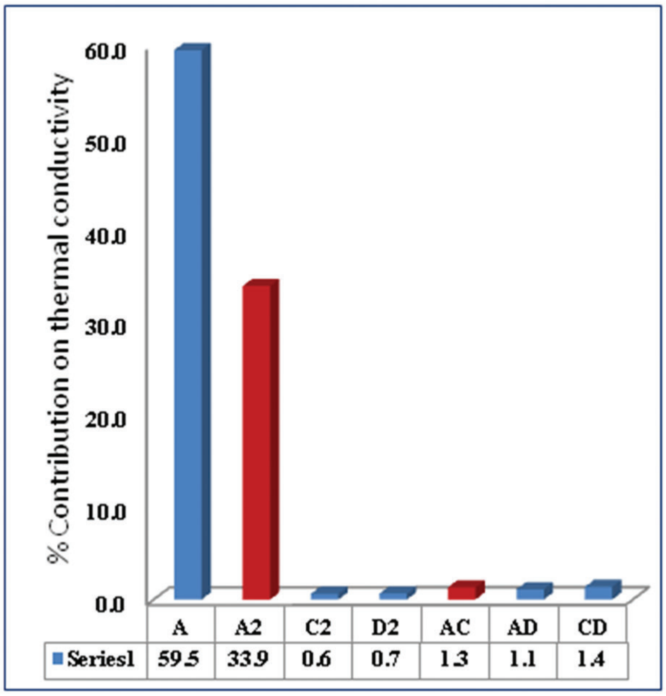
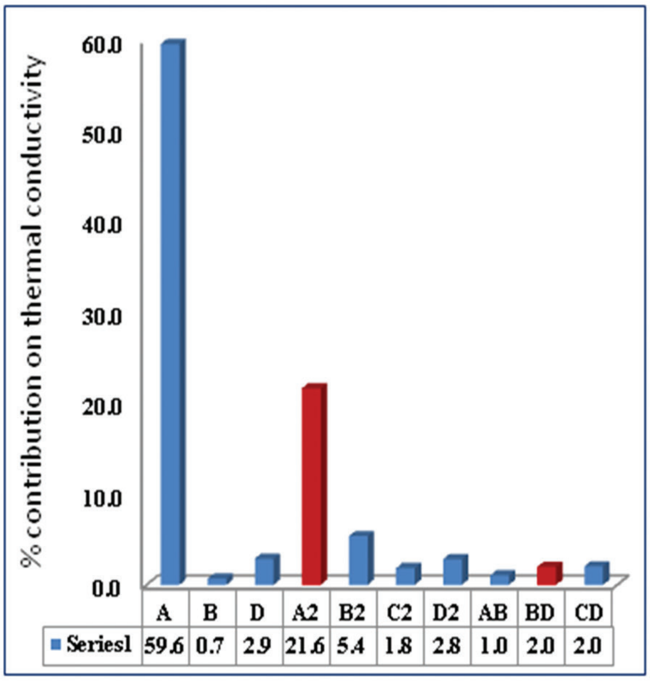


Figure 14: SEM image of HDPE circular sheet fabricated using hydraulic press.



(a)



(b)

Figure 15: Percentage contribution on thermal conductivity for casting process (a) HDPE and (b) PP.

stresses during the interfacial de-bonding mechanism which reduces the energy absorption capability of the matrix polymer casted sheet (Peng et al., 2021).

From Figure 9, it is found that the percentage contribution on MFI of the casted HDPE sheet using extrusion is 11.8% synergistically by the design variable average Barrel temperature. It is also observed that out of all four process variables, the additive concentration (D) contributes a maximum of 46.1% antagonistically on MFI for casted sheets fabricated from HDPE. This negative behaviour on MFI may be understood as on increasing the content of additive (calcium carbonate+ HPMC) the composite viscosity increased due to the formation of agglomerates in the matrix which ultimately reduces the melt flow index (MFI) of the composite sheet (Chaudhary et al., 2021). The same reason can be attributed from the captured SEM images as depicted in Figure 10.

From the study, it was found that the thermal conductivity of fabricated circular was affected positively by the average barrel temperature (A) of the extrusion machine and contributed a maximum of 49.0% as compared to other process variables on thermal conductivity for HDPE sheet. However, an interesting finding observed that its square interaction (A^2) has an antagonistic effect on thermal conductivity. The reason for the antagonistic effect of the square of barrel temperature (A^2) is due to non linear relation of thermal conductivity and temperature. However, this opposite relation still needs more research for better understanding.

Process Optimisation

The optimum condition was determined using optimiser tool in BBD and the obtained results are shown in Table 4. It is found that the theoretically estimated characteristics of a circular sheet made from waste HDPE and PP by using extrusion and hydraulic methods are in good agreement with the experimental values.

Conclusion

In this study, the wastes HDPE and PP were successfully utilised for the fabrication of circular sheets using extrusion and hydraulic press methods. The Box-Behnken design is adopted in order to determine the effect of process parameters on the desired properties such as tensile strength, MFI and thermal conductivity of circular disk applicable for electric circuit breaker plate. The developed non-linear second-order mathematical models are within the close approach to the experimental data. From the study, it was found that average barrel temperature affects synergistically on tensile strength for HDPE and PP sheets. It was also found that this factor also influences the MFI to 11.8% and 6.8% for HDPE and PP circular sheets. It was observed that on increasing the barrel temperature, the thermal conductivity gets affected synergistically. A similar finding was observed for circular disk fabricated by the hydraulic press method. The sheet fabricated using the extrusion process is found to be more competent as compared to the hydraulic press method since under optimum conditions the estimated properties of

Table 4: Optimised conditions of the extrusion process and hydraulic press process parameters

Extrusion operating parameters		*Extrusion responses*					
HDPE & PP		*TS(HDPE), MPa*		*MFI (HDPE), g/10 min*		*T C(HDPE), W/mK*	
Temperature (°C)	100	Optimised	Experimental	Optimised	Experimental	Optimised	Experimental
RPM (m/s)	83	1505.71	1535.49	2.172	2.5689	0.028	0.0312
Size (mm)	1.40	TS(PP)		T C (PP)		MFI (PP)	
Composition (%)	12.55	1097.63	1068.74	2.60	2.45	0.021	0.0286
Hydraulic press operating parameters		*Hydraulic Press responses*					
HDPE & PP		*TS(PP), MPa*		*MFI (PP), g/10 min*		*T C(PP), W/mK*	
Temperature (°C)	145	Optimised	Experimental	Optimised	Experimental	Optimised	Experimental
Pressure (psi)	132	827	836	0.842	0.819	0.3201	0.2972
Size (mm)	1.70	TS(PP)		T C (PP)		MFI (PP)	
Composition (%)	15	669.38	645.75	1.8217	1.6980	0.2669	0.2234

the circular sheet are under the desired range by the extrusion method. Moreover, the thermal conductivity of sheets ranges from 0.028 to 0.031 W/mK for PP and HDPE respectively using extrusion whereas it ranges from 0.223 to 0.297 W/mK for PP and HDPE respectively using the hydraulic press method. Overall, both methods were found to be effective and have great potential in managing polymeric waste for developing value-added products and finally reducing the burden on the environment.

References

Achilias, D.S., Giannoulis, A. and G.Z. Papageorgiou (2009). Recycling of polymers from plastic packaging materials using the dissolution-reprecipitation technique. *Polym. Bull*., **63(3):** 449-465. doi:10.1007/s00289-009-0104-5

Chaudhary, R., Upadhyaya, S. and V.K. Sangal (2021). A parametric study on the HDPE/PP and marble slurry waste utilisation using single screw extruder. *Asian J. Water Environ. Pollut*., **18(4):** 9-17. doi:10.3233/AJW210038

Devasahayam, S., Bhaskar Raju, G. and C.M. Hussain (2019). Utilization and recycling of end of life plastics for sustainable and clean industrial processes including the iron and steel industry. *Mater. Sci. Energy Technol.*, **2(3):** 634-646, doi:https://doi.org/10.1016/j.mset.2019.08.002, 2019.

Liu, A., Ren, F., Lin, W.Y. and J.Y. Wang (2015). A review of municipal solid waste environmental standards with a focus on incinerator residues. *Int. J. Sustain. Built Environ*., **4(2):** 165-188. doi:10.1016/j.ijsbe.2015.11.002

Peng, Y., Musah, M., Via, B. and X. Wang (2021). Calcium carbonate particles filled homopolymer polypropylene at different loading levels: Mechanical properties characterization and materials failure analysis. *J. Compos. Sci.*, **5(11):** 302, doi:10.3390/jcs5110302

Rao, P.V.C.S., Kumarb, M.V. and A. Arunb (2019). Fabrication and testing of Composite tile made from plastic waste and mineral admixture for aggressive environments. *Materials Today: Proceedings*, **15(1):** 90-95.

Saba, N., Paridah, M.T. and M. Jawaid (2015). Mechanical properties of kenaf fibre reinforced polymer composite: A review. *Constr. Build. Mater*., **76:** 87-96. doi:10.1016/j.conbuildmat.2014.11.043

Şimşek, B. and T. Uygunoğlu (2016). Multi-response optimization of polymer blended concrete: A TOPSIS based Taguchi application. *Constr. Build. Mater*., **117:** 251-262, doi:10.1016/j.conbuildmat.2016.05.027

Singh, N., Hui, D., Singh, R., Ahuja, I.P.S., Feo, L. and F. Fraternali (2017). Recycling of plastic solid waste: A state of art review and future applications. *Compos. Part B Eng*., **115:** 409-422, doi:10.1016/j.compositesb.2016.09.013

Singh, R., Singh, N., Fabbrocino, F., Fraternali, F. and I.P.S Ahuja (2016). Waste management by recycling of polymers with reinforcement of metal powder. *Compos. Part B Eng*., **105:** 23-29. doi:10.1016/j.compositesb.2016.08.029

Soy, U., Findik, F., Yetgin, S.H., Gokkurt, T. and F. Yıldırım (2017). Fabrication and mechanical properties of glass fiber/talc/$CaCO_3$ filled recycled PP composites. *Am. J. Appl. Sci*., **14(9):** 878-885. doi:10.3844/ajassp.2017.878.885, 2017.

Sutar, H., Sahoo, P.C., Sahu, P.S., Sahoo, S., Murmu, R., Swain, S. and S.C. Mishra (2018). Mechanical, thermal and crystallization properties of polypropylene (PP) reinforced composites with high density polyethylene (HDPE) as matrix. *Mater. Sci. Appl.*, **09(05):** 502-515. doi:10.4236/msa.2018.95035, 2018.

Turku, I., Keskisaari, A., Kärki, T., Puurtinen, A. and P. Marttila (2017). Characterization of wood plastic composites manufactured from recycled plastic blends. *Compos. Struct*., **161:** 469-476. doi:10.1016/j.compstruct.2016.11.073

Asian Journal of Water, Environment and Pollution
Volume 20 Number 3 **May, 2023**

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