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A Parametric Study on the HDPE/PP and Marble Slurry Waste Utilisation Using Single Screw Extruder

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Abstract: Due to the increased socio-economic development, the manufacturing of different products based on various polymers for different applications such as space crafts, airplanes, automobiles, boats, and sports equipment are increasing continuously. This huge increase in solid polymer commodities is also creating the extravagant quantity of solid waste polymers (SWPs) due to their non-degradable characteristics. These SWPs, for example, high-density polyethylene (HDPE), polypropylene (PP), low-density polyethylene (LDPE), and nylon, etc., are used frequently in various applications and create new challenges to the industries, government, as well as end-users for systematic waste recycling/recovery in an eco-friendly manner. Moreover, in this modernisation era, almost all marble industries are also facing a huge problem as marble slurry (MS) yields a great burden not only due to its limited degradability characteristics but also wider environmental hazard towards water bodies, and rivers. Fine particles in the range size of 45-300 micron in the MS create air pollution which in turn increases breathing problems. Moreover, it also creates an ecological adverse impact on soil fertility and reduces the percolation rate of rain water which in turn reduces the recharging of groundwater. Therefore, keeping in view the above facts, the simultaneous recycling of HDPE, PP and marble slurry is adopted through single screw extrusion in order to reduce the burden on the environment. Moreover, the effect of various process parameters viz barrel temperature, screw speed (rpm), feed composition, and grain size of PP and HDPE on extrudate output was envisaged. It was found that the extrudate output increases steeply on increasing the average barrel temperature from 100 to 120°C and linearly with screw speed range from 65 to 85 rpm. The effect of grain size had shown decreasing trend in throughput whereas on increasing the polymer content in the feed, throughput was found to be enhanced. Additives such as HPMC were found to be effective when used in synergy with HDPE and PP along with MS. The extrudate throughput was found to be a maximum of 33.01 g/minute at 120°C, 85 screw rpm, 1.40-grain size underfeed with equal proportionate of HDPE/PP with 2% HPMC and 8% MS. This clearly opens the ways for proper utilization of HDPE, PP and MS waste by extrusion and provides the environmental protection solution by utilizing these polluted materials in the fabrication of value-added products through extrusion.

Key words: Extrusion, recycling, HDPE, air pollution, marble slurry, water pollution.

Introduction

Engineering materials play a protruding role in modern civilization. With the increased responsiveness of the society, there is a constantly growing concern in using materials considering environmental viewpoints as well. Therefore, in recent years, a huge amount of literature has been published on the preparation of new materials to promote sustainable development. Sustainability covers various aspects within the field of materials engineering, including the possibility to recycle waste materials such as polymer waste and marble waste.

Types of waste generated from various industries may be categorised as municipal solid waste, chemical

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waste, domestic waste (biodegradable waste and non-biodegradable waste), industrial waste, medical waste, and polymer waste, etc. Few of these are very hazardous and burden on the ecosystem (Liu et al., 2015). Although, several methods were followed by many industries to eradicate waste, few wastes, like polymers, are difficult to characterise due to their complex chemical structure. Treatment of these wastes may generate various harmful gases which may cause a threat to human as well as aquatic bodies.

Numerous recycling techniques are generally adopted to manage polymer waste which is based on post-consumer-based products. Recycling is the process that decreases the amount of discharge of the waste stream. Recycling includes mainly four processes particularly collection, separation, reprocessing and marketing (Shent et al., 1999). The four types of recycling processes involved are namely primary, secondary, tertiary (chemical, pyrolysis) and quaternary (incineration). Primary and secondary may be catergorised as mechanical recycling strategies because it consists of recycling polymer through manner of means of heating material as much as positive temperature and converting its physical shape. But tertiary (chemical and ryrolysis) and quaternary (incineration) recycling processes include quite specific criteria. In pyrolysis, by-products obtained are of high calorific values; however, they consume excessive energy during recycling. In quaternary recycling incineration with heat recovery utilised frequently for few plastics like PVC ought to be eliminated because harmful gases are emitted in the environment when these plastics are burnt.

An increase in polymer waste is a vital responsible aspect for the hike in production of solid waste with direct influence on the environment (Singh et al., 2016). In India, the annual consumption of polymer has been increased up to thirty times, from 50 million tonnes to 350 million tonnes. Highly flexible nature of these polymeric substances, which are lighter than competing substances and tailor-made potential are the main motive behind their utilisation. This large increase in solid polymer commodities is also generating an excessive quantity of solid waste polymers (SWPs). A further boom in polymer waste is developing strain in the confined space (Molgaard et al., 1995). Only the packaging of the materials creates about 141 million tonnes of plastic waste.

Besides polymer waste, marble is a commonly used material due to its aesthetic characteristics, especially in the area of civil engineering and commonly used natural stone around the world. According to the valuations, approximately 500 million metric tons of marble stone are mined annually. Half of which comes from the mines of four countries, namely India, Italy, China and Spain. India accounts for roughly 10% of the global extraction which makes it the third-largest producer. About 85–90% of the Indian marble is mined from the Rajasthan region. The processing of marble leads to the generation of a huge amount of waste in the form of slurry which results both in financial loss as well as creates environmental pollution towards air, water and soil.

Therefore, some synergistic approach is yet to be modified in order to utilise the polymer waste and marble slurry (MS) through recycling. Most of the polymer waste is popping out of post-consumer-based plastic materials. Hence, post-ingested plastic substances may find new opportunities within the vicinity of new product development.

Basically, recycling is a rising issue in recent years due to the wide use of plastic (Taylor et al., 2007). The reason behind this growth is strength, user-friendly design, fabrication capabilities and low density. Researchers have studied different recycling strategies to prepare products like plastic lumber (Breslin et al., 1998; Singh et al., 2017), composites with the aid of using reinforcing metallic/ceramic substances, etc (Singh & Singh, 2016). Reinforcements in polymer material can only be done by the use of mechanical recycling (Turner et al., 2018).

Various researchers (Deka & Maji 2011; La Mantia & Morreale, 2011; Shent et al., 1999; Singh et al., 2016) have developed mechanical and chemical techniques in order to recycle these polymers wastes. In this series, Deka and Maji (2011) prepared wood plastic composite by blending HDPE, poly-propylene (PP), poly vinyl chloride (PVC), wood flour, modified montmorillonite (MMT) and glycidyl methacrylate (GMA). Recycled plastic may also be used as resin. Turner et al. (2018) used plastic waste for the synthesis of re-formative polymer composites for its possible application in utility poles, railway sleepers, and fencing. Some recycled polymers have established a great market value in the field of composites, auto parts, soil reinforcement (Murray et al., 2000; Yang et al., 2019), artificial implants, healthcare applications, medical delivery systems, elimination of microorganism and water desalination (Alan et al., 2015; Sutar et al., 2018).

However, in mechanical recycling, only segregation of different types of polymer management is possible which only help in detecting the plastic or polymer from the huge stock of the waste, but on the other hand, chemical recycling needs reactors and numerous chemicals to break the polymer into monomers and requires a lot of energy input. Therefore, it is noteworthy that suitable techniques should be extruded to convert the polymer waste into the same value-added products, which not only decreases the burden on earth but also make the process energy efficient as compared to mechanical and chemical recycling techniques (Erenkov et al., 2010).

Findik and Yetgin (2017) have utilized recycled polypropylene (RPP) granules and then compounded glass fibre/talc/$CaCO_3$ additives with RPP granules using extrusion. Mashaly et al. (2016) studied the effect of characterisation of marble slurry waste generated which was carried out during the ornamental stone processing operations and the marble slurry was used as cement replacement in the fabrication of concrete blocks.

In this study, the polymer wastes such as high-density polyethene (HDPE) and polypropylene (PP) were recycled using an extrusion process and efforts were made to convert these wastes into value-added products, namely, circular disk using various additives such as HPMC, waste marble slurry. Moreover, the effect of process parameters such as average barrel temperature, screw speed of extruder, grain size and composition on extrudate throughput were carried out for better understanding the extrusion process. Most of the earlier studies had not considered the effect of grain size in processing, however, grain size plays an important role in the extrusion process due to the involvement of chemical interaction and morphology. Therefore, in the present study, the effect of polymer grain size on extrudate throughput was also taken into account. The synergistic effect of recycled PP and HDPE was also analysed for better and simultaneous utilisation of waste using the extrusion process. Moreover, the effect of HPMC additive during processing was also investigated.

Materials and Experimental Methods

In this section, chemical, plastic waste and extrusion processes were described in detail.

Materials

Various substances used in this study could be defined under the following categories, namely polymer waste of HDPE and PP, additive as hydroxy-propyl-methyl-cellulose (HPMC), and marble waste in the form of marble slurry. A nonlinear polymer HDPE and PP were collected from the laboratory container waste. Whereas marble slurry of 100 and 200 mesh size were collected from the marble industry site and HPMC additive was purchased from Sita Chemical of LR grade.

Extrusion

The schematic diagram of a single screw extruder is illustrated in Figure 1. Extrusion is a high-volume manufacturing process where the plastic material is melted with the application of heat and extruded via die into a mould of the desired shape. A cylindrical rotating helical flight crew as indicated in Figure 1 is located in the barrel which forces out molten plastic material through a die. The extruded material takes shape according to the cross-section of the die.

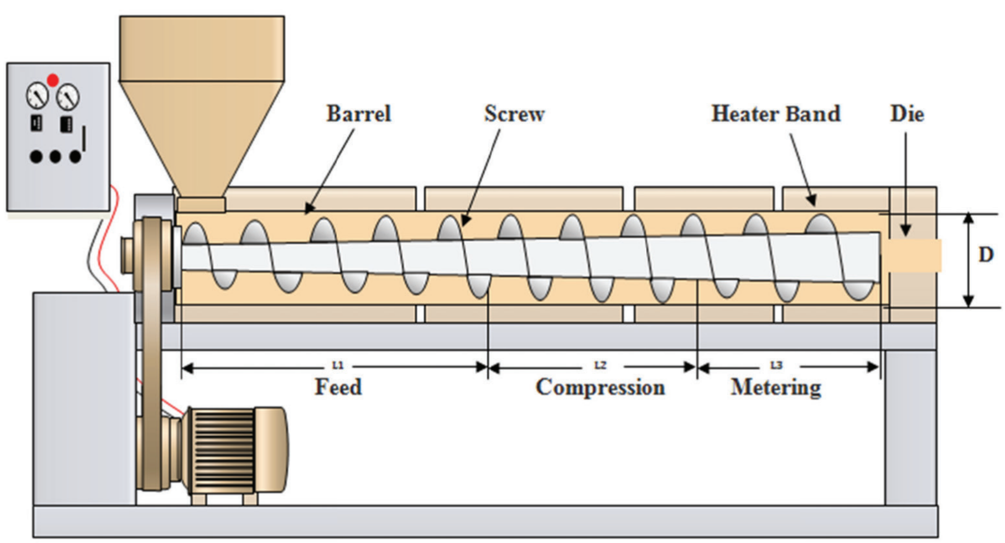

Figure 1: Single screw extruder.

Experimental Procedure

The complete line diagram for recycling plastic and marble slurry waste through the extrusion process is illustrated in Figure 2. In this process, various grain sizes of HDPE/PP waste were prepared from the shredder and then fed individually or simultaneously into the feed hopper of the extruder where preheating was done in order to make these pellets soft. Thereafter, HPMC as an additive and MS were mixed initially in the mixer and then injected slowly through the injector near the feed section of the extruder adjacent to the hopper. The three-band heaters situated on the upper surface of the barrel underfeed, compression and metering section along the length of the screw were used for softening, chain scission, and melting of polymer respectively in order to aid homogeneous mixing of polymer melt with additive and MS. The average barrel temperature was kept under the range of 100 to 120°C. Continuous extrudate has been taken into the mould to give shape to the circular disk. The overall process starts after half an hour once the set temperature was attained for ease in processing. The melt originates from the die section of the extruder and was weighed for throughput estimation and testing purposes.

Results and Discussions

The effect of process parameters namely barrel temperature, extruder screw rpm, additives concentration and grain size on extrudate output were explored in the subsequent sections. Moreover, the synergistic effect of recycled HDPE and PP was also discussed in detail for better and simultaneous utilisation of waste using the extrusion process.

Effect of Barrel Temperature on Extrudate Throughput

The effect of average barrel temperature on extrudate output is represented in Figure 3 at a polymer grain size of 2.36 mm. It is evident from Figure 3 that on increasing the average barrel temperature from 100°C to 120°C, the extrudate output of 100% recycled HDPE was increased from 9.62 to 23.12 gm/minute and 17.98 to 33.87 gm/minute under 65 rpm and 85 rpm, respectively. Similarly, for 100% recycled PP, it increased from 7.931 to 18.874 gm/minute and 15.87 to 29.69 gm/minute under 65 rpm and 85 rpm respectively. Moreover, it is also depicted that on using 10% additives comprising 2% HPMC and 8% MS by

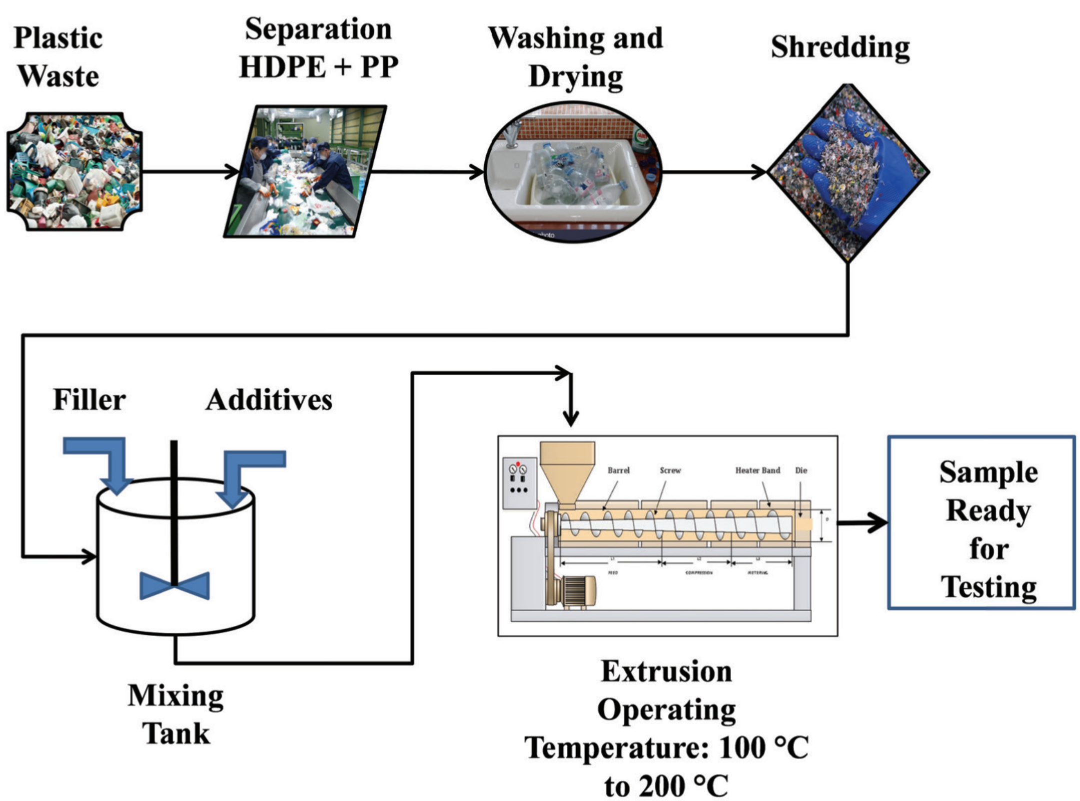

Figure 2: Recycling, shredding and extrusion process flow line diagram.

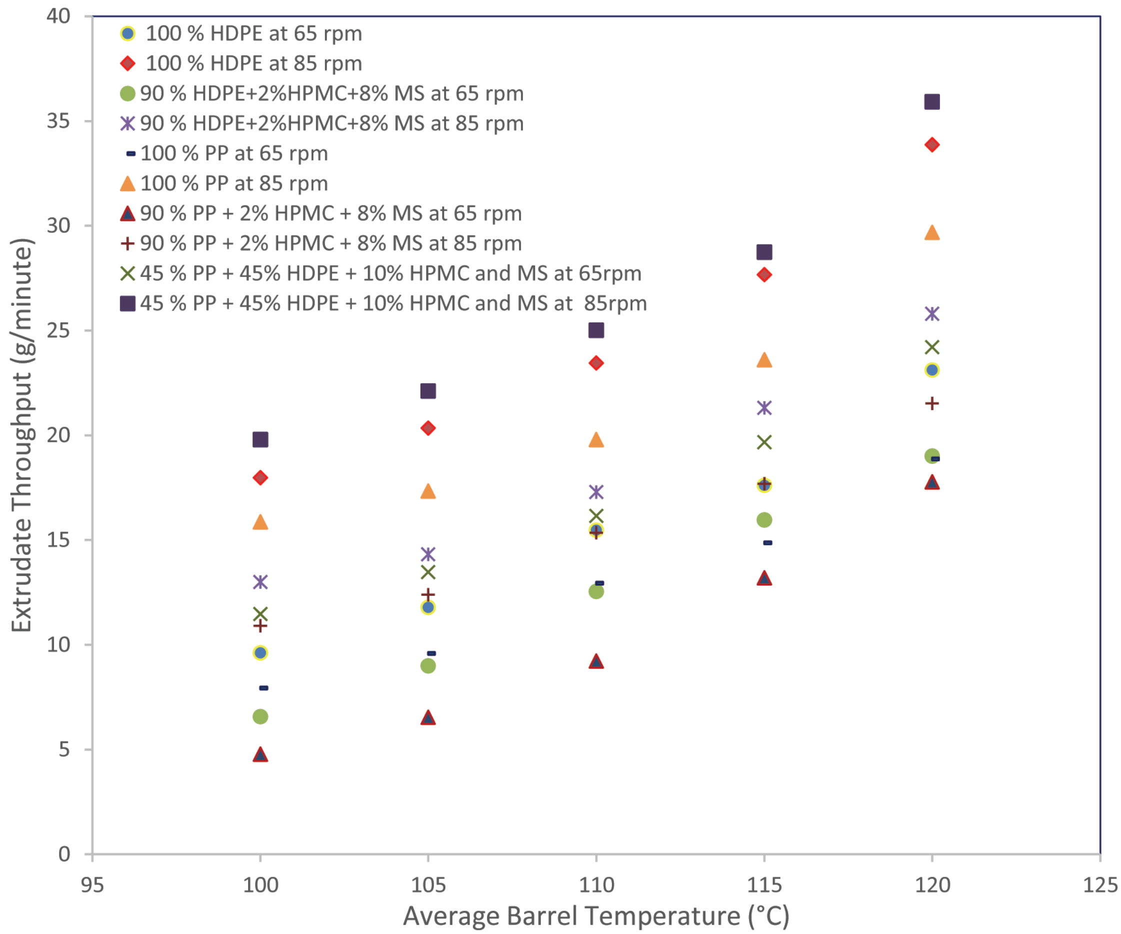

Figure 3: Effect of average barrel temperature on throughput.

weight in recycled HDPE and PP pellets individually, the extrudate output for additives mixed HDPE increased from 6.56 to 19.01 gm/minute and 13.006 to 25.6 gm/minute on increasing the average barrel temperature from 100°C to 120°C under 65 rpm and 85 rpm, respectively, whereas for PP, it increased from 4.78 to 17.78 gm/minute and 10.91 to 21.53 gm/minute under 65 rpm and 85 rpm respectively. Furthermore, the synergistic effect of HDPE and PP were also examined and it is obvious from Figure 3 that extrudate output increased from 11.47 to 24.21 gm/minute and 19.79 to 35.92 gm/minute for equally mixed HDPE and PP with 10% additives (HPMC+MS) under 65 rpm, and 85 rpm. Moreover, it is observed that the trend of increment in extrudate throughput is exponential, which may be attributed to the reason that the melt viscosity of the polymer shows exponential temperature dependence (Cao et al., 2020). For deeper understanding, it may be concluded that the shear-thinning phenomena might get increased tremendously on the increasing temperature in the metering section due to high shearing as a result of faster polymer melting and homogenous mixing inside the barrel. It is also found that the extrudate output of HDPE is higher as compared to PP under the same operating conditions. This may be because the processing and melting temperature of HDPE are far below that of PP. It is known that on adding additives to the polymer, the processing becomes easier, however, it is observed from Figure 3 that extrudate output decreases slightly on using 10% additives. This decrement is due to the antagonistic behaviour between HPMC and MS. The latter additive MS is predominant on HPMC as a result throughput is suppressed to some extent. The synergistic effect of recycled HDPE/PP shows the interesting result as extrudate output is higher than individual polymers as well as while using additives with individual polymers under constant respective parameters. This may be attributed to that HPMC gets attached with both HDPE and PP during shearing due to chain scission which in turn creates homogenous mixing between them in the compression and metering section of a single screw extruder.

Effect of Screw Speed on Extrudate Throughput

The effect of screw rpm of extruder on extrudate throughput is represented in Figure 4. It is obvious from Figure 4 that on increasing the screw rpm from 65 rpm to 85 rpm, the extrudate throughput of 100% HDPE (recycled) increased from 9.62 to 17.98 gm/minute and 23.12 to 33.87 gm/minute at 100°C and 120°C, respectively. Similarly, for PP, throughput increased from 7.931 to 15.421 gm/minute and 18.874 to 29.69 gm/minute at 100°C and 120°C, respectively. While using 10% additives (2%HPMC+8%MS) in recycled pellets of HDPE and PP separately in extrusion, it is observed that extrudate throughput gets increased from 6.568 to 13.006 gm/minute and 19.01 to 25.8 gm/m at 100°C and 120°C, respectively, on increasing the screw rpm from 65 to 85 whereas for PP it increased from 4.78 to 10.91 gm/minute, and 17.78 to 21.53 gm/minute at 100°C and 120°C, respectively. Moreover, the mutual interactive effect was also studied between PP and HDPE when mixed in equal proportionate with 10% total additives on extrudate throughput. It is observed that on increasing the screw rpm from 65 to 85, the throughput increased from 11.47 to 19.79 gm/minute, and 24.21 to 35.92 gm/minute at 100°C and 120°C, respectively. The increment in the extrudate output can be corroborated by the fact that on increasing the screw rpm, the melt viscosity decreases due to the creation of thermal and frictional stresses on the polymer melt. It is observed that by using 10% additives in HDPE and PP, respectively, the throughput increased gradually while at higher rpm it increased steeply. This may be due to the reason that at lower rpm, MS may not mix properly in the polymer matrix as compared to HPMC, while at higher screw rpm, additional stresses help in breaking the polymer viscosity due to thermal and viscous energy dissipation, in turns, MS mixed faster and shows the heavy dependency of throughput on screw rpm. Moreover, the synergist effect of recycled HDPE/PP shows a commendable observation that

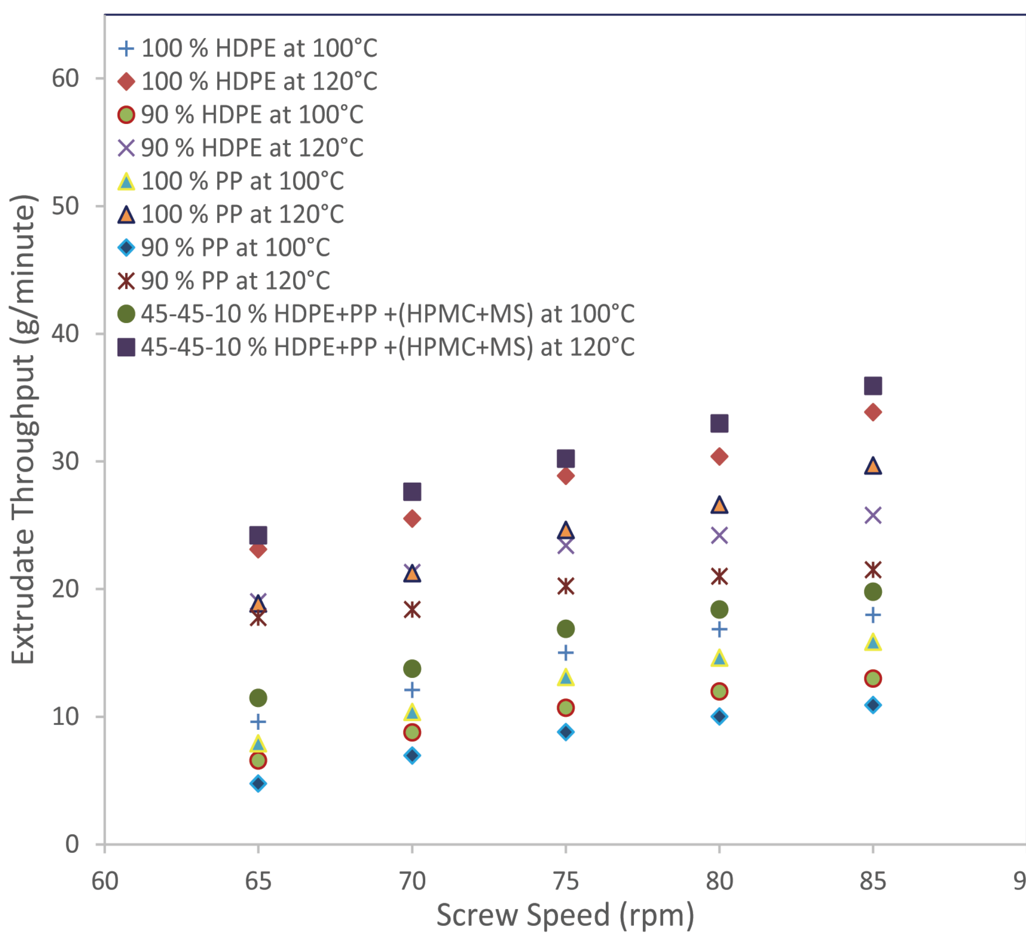

Figure 4: Effect of screw speed on throughput.

extrudate throughput increased steeply as compared to individual polymers as well as additives with polymers. This interesting outcome is because the functional group of HPMC aids in increasing the chemical interaction between the carbon-carbon chain and functional groups of HDPE and PP with the hydroxyl group of HPMC. The cellulose present in the HPMC also tends to bind the MS and helps in homogeneous mixing. This high rate of extrudate throughput is only possible due to the thermal and chemical dynamics phenomena during the extrusion process.

Effect of Grain Size on Extrudate Throughput

It is known that grain size plays a vital role in the extrusion process therefore, the effect of polymer grain size on extrudate throughput is manifested in Figure 5. It is shown in Figure 5 that on increasing the grain size of polymer from 1.40 mm to 2.80 mm, the extrudate output decreased from 17.984 to 3.2 gm/minute and 31.003 to 13.82 gm/minute at 100°C and 120°C, respectively, for 100% HDPE (recycled), whereas for 90% HDPE +2% HPMC+8% MS, it decreased from 13.957 to 3.55 gm/minute and 27.439 to 11.81 gm/minute at 100°C and 120°C, respectively, for 90% HDPE +2% HPMC+8% MS. Similarly, from the Figure 5, it is observed that extrudate throughput of 100% PP (recycled) decreased 21.73 to 3.6 gm/minute and 29.89 to 10.1 gm/minute at 100°C, and 120°C respectively whereas it decreased from 17.627 to 1.68 gm/minute and 30.90 to 10.02 gm/m at 100°C, and 120°C respectively for 90% PP+2% HPMC+8% MS. Moreover, it is also found that the throughput decreased from 23.95 to 4.3 gm/minute and 33.00 to 17.47 gm/minute at 100°C, and 120°C respectively for HDPE (45%)+PP (45%) +HPMC (8%)+ MS (2%). This decrement in throughput may be attributed by the fact that higher grain size of polymer needs extra efforts from extruder screw and barrel heaters in order to increase melting mechanism. Moreover, available time is insufficient to melt the polymer homogeneously within screw channel in turn throughput ceases.

Effect of Composition on Extrudate Throughput

The effect of feed composition of extrudate output is shown in Figure 6. It is found from Figure 6 that on increasing the polymer composition from 80 to 100%, the throughput of HDPE and PP increased from 3.009 to 9.62 gm/minute and 6.205 to17.98 gm/minute at 65 and

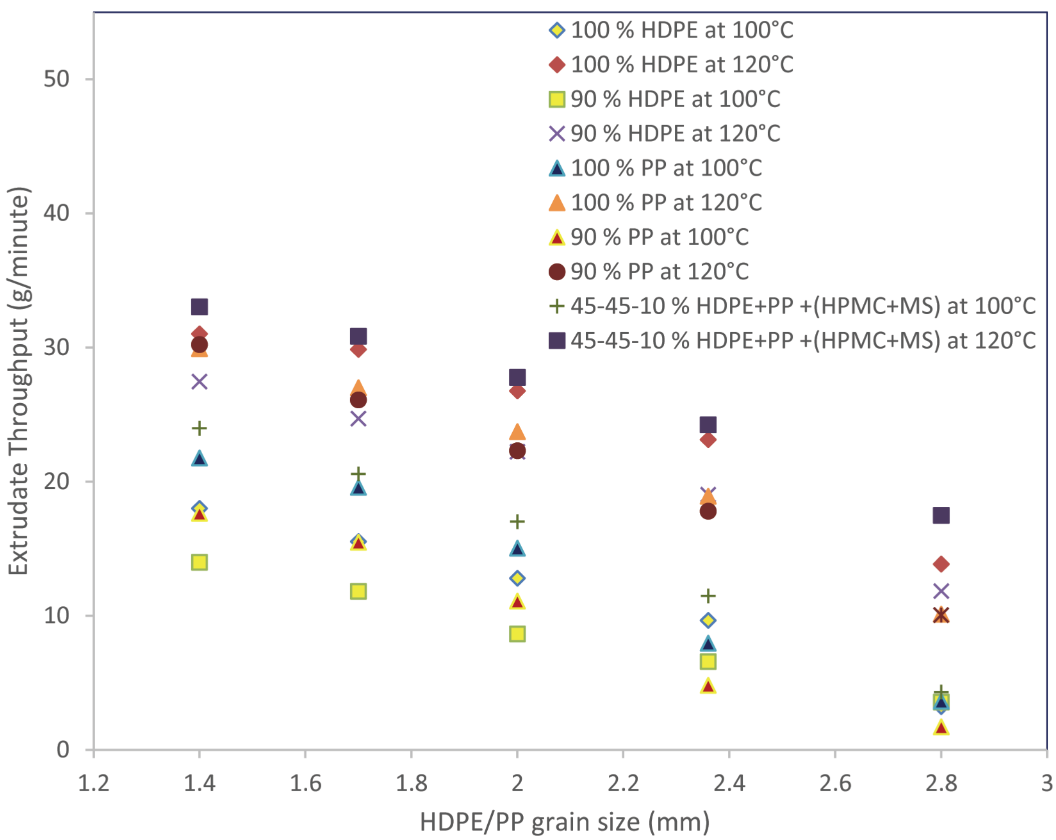

Figure 5: Effect of grain size on etrudate throughput.

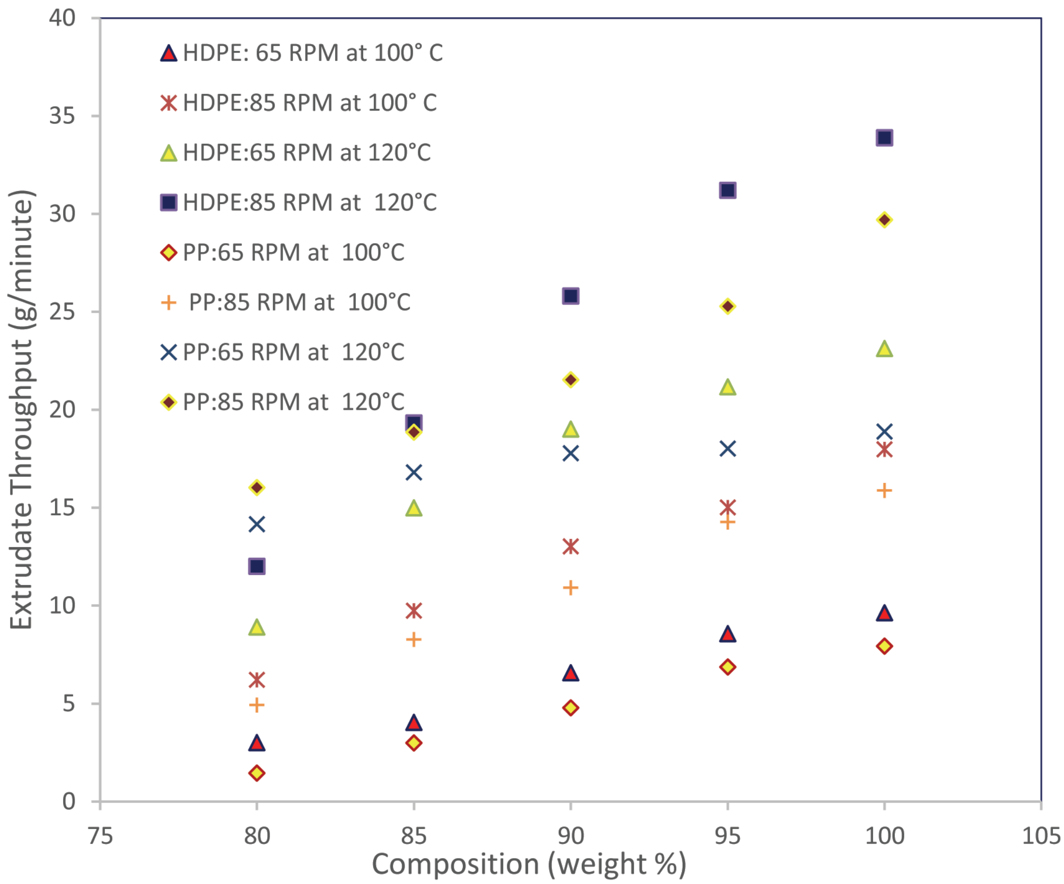

Figure 6: Effect of feed composition on extrudate throughput.

85 rpm respectively under average barrel temperature of 100°C. Moreover, the same increasing pattern is observed from 8.908 to 23.12 gm/minute and 12.006 to 33.87gm/mat 65 rpm and 85 rpm screw speed under 120°C of average barrel temperature. A similar finding for PP is also shown in Figure 6. These increments in extrudate throughput can be understood as the additive MS composition decreases on increasing the polymer content. Another thermodynamic observation is found that at lower rpm and barrel temperature, the increasing trend is linear whereas at higher rpm and barrel temperature the profile is exponential. These may be because the viscosity dissipation rate and molecular shear stress in the polymer melt are less at lower screw speed and barrel temperature whereas at higher screw speed, the thermal and viscous stresses develops at a high rate in addition due to higher barrel temperature which tends the polymer mixture into homogeneous melt with rapid rate as in turns increases the throughput. This can also be understood as the viscosity decreases exponentially with barrel temperature and shearing for the non-Newtonian fluid.

Conclusions

The effect process parameters such as average barrel temperature, screw speed, the grain size of feed and feed composition were studied systematically on the extrudate throughput of HDPE (recycled), PP (recycled) and HDPE/PP synergy from a single screw highly instrumented extruder. It was found that the extrudate output shows exponential increment on increasing the barrel temperature. However, linear increment in throughput was encountered with screw speed. On the other hand, the extrudate throughput was found to decrease rapidly on increasing the grain size of polymers whereas it increased on increasing the polymer content in the feed. Moreover, at higher screw speed and barrel temperature, the exponential increment in extrudate throughput was envisaged whereas linear increment encountered at lower on increasing the polymer content in the feed. The synergistic effect of HDPE/PP with additives was also studied and revealed that the extrudate output was higher than individual polymers as well as while using additives with individual polymers on increasing the barrel temperature, which clearly proclaims the waste utilisation of marble slurry in the fabrication of value-added product.

References

Alan, S., Sivagnanaprakash, B., Suganya, S., Kalaiselvam, A. and V. Vignesh (2015). A study on mechanical properties of fly ash brick with waste plastic strips. *Int. J. Appl. Res.,* **(10):** 183-192.

Breslin, V.T., Senturk, U. and Berndt (1998). Long-term engineering properties of recycled plastic lumber used in pier construction. *Resour. Conserv. Recycl.*, **23(4):** 243-258.

Cao, Z., Chen, M., Han, X., Yu, J., Wang, R. and X. Xu (2020). Evaluation of viscosity-temperature characteristics and rheological properties of rejuvenated SBS modified bitumen with active warm additive. *Constr. Build. Mater.,* **(236):** 117548.

Deka, B.K. and T.K. Maji (2011). Study on the properties of nanocomposite based on high density polyethylene, polypropylene, polyvinyl chloride and wood. *Compos. Part A Appl. Sci. Manuf.,* **42(6):** 686-693.

Erenkov, O.Y., Igumnov, P.V. and V.L. Nikishechkin (2010). Mechanical properties of polymer composites. *Russ. Eng. Res.,* **30(4):** 373-375.

Gondal, M.A. and M.N. Siddiqui (2007). Identification of different kinds of plastics using laser-induced breakdown spectroscopy for waste management. *J. Environ. Sci. Heal. - Part A Toxic/Hazardous Subst. Environ. Eng.,* **42(13):** 1989-1999.

La Mantia, F.P. and M. Morreale (2011). Green composites: A brief review, *Compos. Part A Appl. Sci. Manuf.,* **42(6):** 579-588.

Liu. L., Ren, F., Lin, W.Y., and J.-Y. Wang (2015). A review of municipal solid waste environmental standards with a focus on incinerator residues. *International Journal of Sustainable Built Environment.,* **4(2):** 165-188.

Mashaly, A.O., El-Kaliouby, B.A., Shalaby, B.N., El-Gohary, A.M. and M.A. Rashwan (2016). Effects of marble sludge incorporation on the properties of cement composites and concrete paving blocks. *J. Clean. Prod.,* **112(1):** 731-741.

Mølgaard, C. (1995). Environmental impacts by disposal of plastic from municipal solid waste. *Resour. Conserv. Recycl.,* **15(1):** 51-63.

Murray, J.J., Frost, J.D. and Y. Wang (2000). Behaviour of a sandy silt reinforced with discontinuous recycled fiber inclusions. *Transp. Res. Rec.,* **(1714):** 9-17.

Shent, H., Pugh, R.J. and E. Forssberg (1999). A review of plastics waste recycling and the flotation of plastics. *Resour. Conserv. Recycl.,* **25(2):** 85-109.

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.

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.

Singh, S. and R. Singh (2016). Robotics and computer-integrated manufacturing effect of process parameters on micro hardness of Al–Al_2O_3 composite prepared using an alternative reinforced pattern in fused deposition modelling assisted investment casting. *Robot. Comput. Integr. Manuf.,* **37:** 162-169.

Soy, U., Findik, F., Yetgin, S. H., Gokkurt, T. and Y. Ferhat (2017). Fabrication and mechanical properties of glassfiber/talc/$CaCO_3$ filled recycled PP composites. *Am. J. Appl. Sci.,* **14(9):** 878-885.

Subramanian, P.M. (2000). Plastics recycling and waste management in the US. *In Resources, Conservation and Recycling*, **(28):** 253-263.

Sutar, H., Sahoo, P.C., Sahu, P.S., Sahoo, S., Murmu, R., Swain, S. and S. Mishra (2018) Mechanical, thermal and crystallization properties of polypropylene (PP) reinforced composites with high density polyethylene (HDPE) as matrix. *Mater. Sci. Appl.,* **(5):** 502-515.

Turner, R.P., Kelly, C.A., Fox, R. and B. Hopkins (2018). Re-formative polymer composites from plastic waste: Novel infrastructural product application, *Recycling,* **3(4):** 1-16.

Yang, G., Park, M. and S.J. Park (2019). Recent progresses of fabrication and characterization of fibers-reinforced composites: A review. *Compos. Commun.,* **14:** 34-42.