Recycling of plastic solid waste:
A state of art review and future applications

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Abstract

Plastic solid waste (PSW) of polymers (like: high density polyethylene (HDPE), low density polyethylene (LDPE), Nylon etc.) is creating new challenges, which in today's scenario are major research concerns. A sharp rise has been observed in production of different products based on different plastic material. This huge increase in plastic commodities also increases the waste generation thus creating new challenges. Some researchers have reported work in the field of PSW management with different recycling methods. This paper compiles the different research work done by researchers in this field of recycling and progress in recovery and management of PSW by different methods (i.e. Primary, secondary, tertiary and quaternary) along with the various identification/separation techniques. Further, this paper reviews the effect on properties of virgin and recycled HDPE/LDPE/Nylon PSW with different reinforcements like sand, natural fibre, hemp fibre, metal powder etc.

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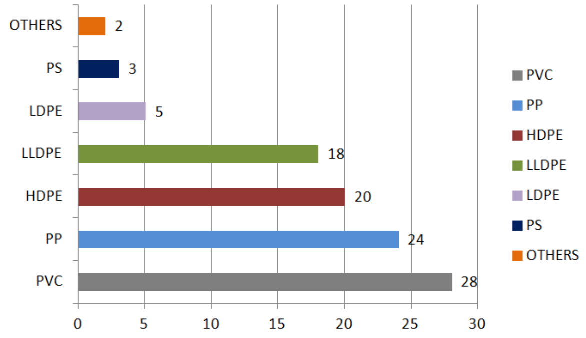
1. Introduction

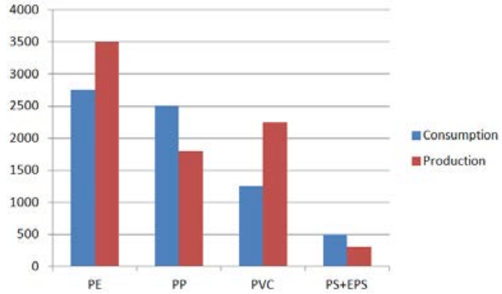
In today's scenario recycling/recovery/management of the plastic solid waste (PSW) is a matter of concern. Industries are getting more interested in the field of plastic manufacturing; so many commodities are being manufactured with plastics. Plastics have become a crucial part of lifestyle, and the global plastic production has increased immensely during the past 50 years (Gu and Ozbakkaloglu, 2016). Traditional plastics are very strong and not readily degraded in the ambient surroundings. It is a fact that plastics will never degrade and remains on landscape for several years. Polymer needs hundreds of years to degrade in normal environmental conditions (Pol and Thiyagrajan, 2010). Plastic waste is harmful as its pigment contains many trace elements that are highly toxic (Gondal and Siddiqui, 2007).As a result, environmental pollutants from synthetic plastics have been identified as a huge hassle (Zhen et al., 2005). PSW is being produced on a massive scale worldwide and its production crosses the 150 million tonnes per year globally. In India approximately 8 Million tonnes plastic products are consumed every year (2008) which is expected to rise 12 million tonnes by 2012. Plasticized PVC has a common use manufacturing of pipes, window framing, floor coverings, roofing sheets, and cables; thereby it is discarded at a high rate (Janajreh et al., 2015). Its broad range of application is in packaging films, wrapping materials, shopping and garbage bags, fluid containers, clothing, toys, household and industrial products, and building materials. Further, the recycling of a virgin plastic material can be done 2 to 3 times only, because, after every recycling, the strength of plastic material is reduced due to thermal degradation. Particularly, solvents with a hydrogen donor capability take part in the thermal degradation of polymers affecting the hydrocarbon yield and distribution (Vincente et al., 2009). It is to mention that no authentic estimation is available on the total generation of plastic waste, however, considering 70% of total plastic consumption is discarded as waste, thus approximately 5.6 million tons per annum (TPA) of plastic waste is generated in the country, which is about 15342 tons per day (TPD) (CPCB). A survey was conducted to analyse demand break up of plastic by types showed in Fig 1.



(Source: Chemicals & Petrochemical Statistics, Analysis by Tata Strategic)

Fig. 1 Demand breakup of plastic

From this bar graph, it can be clearly seen that PVC, PP and HDPE contribute more toward the consumption of plastic. Consumption of plastic is readily increasing due to various advantages coming from versatility, low cost and high chemical stability (Passamonti and Sedran, 2012). Polyethylene and polypropylene are a major component of plastic waste from domestic refuse (Aboulkas et al., 2010). More the consumption more is the need of recycling for reduction of use of virgin material. Major raw material for plastic commodities is HDPE (high density polyethylene) / LDPE (low density polyethylene) and nylon. Plastic is a significant fraction of municipal solid waste and often consists of packaging waste and discarded tools and goods (Astrup et al., 2009). Because of this nature, it cannot be thrown in environment as such. This Figure is getting worse as new products are being introduced on a daily basis. This could be very dangerous for the environment and earth. The earth is also experiencing problems because of this plastic waste. In a study it was found that greenhouse gases are being emitted by fossil fuels as methane and carbon dioxide. It is worth noted that carbon emitted as methane gas has 21 times more global warming potential than being emitted as carbon dioxide (Ackerman, 2000). Consumption and production of plastic polymer are based on demand and supply. But in India consumption and production of various plastic polymers is not equal. In India plastic consumption is 9.7 kg/person. Fig 2 shows the report generated by Tata strategic on consumption and production of various plastic wastes.



(Source: Govt. of India Statistics, Analysis by Tata Strategic)

Fig.2 Statistics on consumption and production of various plastic materials (TPA)

It can be clearly seen from this data that consumption and production of polymer faces some huge gap. To fill these gaps usage of virgin material is getting high. Use of plastic product can only be reduced up to certain extent but use of new material for manufacturing can be reduced by using recycling and managing techniques. So many researchers have reported work on recycling and recovery of PSW. Central pollution control board, Delhi stated in a report that 90% of the PSW are recyclable. The 80 % of post consumer based plastic is sent to the landfill, 8% is incinerated and 7% is recycled. Land filling of HDPE has serious consequences as production of GHG (green house gas) so, by using different methods PSW can be made suitable for further applications. Besides the environmental issues with land filling, the disposal of large amounts of remnant cloth is a huge waste of resources and energy (Lv et al., 2015). By reinforcing different particles application domain of the recycled plastic can be increased. It can be used to make particle board as wood based particle boards are made compressing different layers by applying some glue or resin which contains urea formaldehyde and this formaldehyde has potential for increasing various kinds of diseases as well as cancer (Atuanya et al., 2011). Deka et al., 2011 prepared wood plastic composite by blending of HDPE, polypropylene (PP), poly vinyl chloride (PVC), wood flour, modified MMT and glycidyl methacrylate (GMA). So recycled plastic may also be used as resin. Recycling of material can be done by various different techniques i.e. Primary, secondary, tertiary and quaternary. (Al-Salem et al., 2011). With technological advancements in industry all types of polymers and metals can be recycled (Metin et al., 2003). Some researchers have put down three methods of recycling of plastic. First is mechanical separation of plastic waste suitable for secondry use. The second method has two further sub parts; first is energy recovery by incineration and second way is pyrolysis for use as fuels or as polymer feedstock. The third method is taking polymer up to biodegradation level, but that highly depends on type and environmental conditions (Hamad et al., 2013). After this it can be concluded that plastics are majorly contributing towards municipal and industrial waste. In this paper effort has been put on for processing of the different plastic based materials and their recycling methods.

2. Global issues

PSW is a major contributing factor towards the waste generated on a global level. Disposal of polymer is becoming a global issue due to high production and consumption of polymer materials (Sarkar et al., 2012). Many countries have their different waste generation level based on their income level become a serious issue for disposal and management of PSW. Management of waste is a complex process because of the requirement of various information from different sources such as influencing factors in waste generation, forecasts of vast quantities and reliable data (Grazhdani, 2016). In Eastern and Central Asia, the waste generated per year is at least 93 million tonnes. The per capita waste generation ranges from 0.29 to 2.1 kg per person per day, with an average of 1.1 kg/capita/day (OECD report 2010). The Organization for Economic Co-operation and Development (OECD) is an international economic organization of 34 countries which includes AFR (Africa region), SAR (south Asia region), MENA (Middle East and North Africa), ECA (Eastern and Central Asia), LAC (Latin America and Caribbean), EAP (East Asia and the Pacific Region), OECD (Organization for Economic Co-operation and Development) founded in 1961 to stimulate economic progress and world trade. Fig 3 shows the waste generation of various regions.

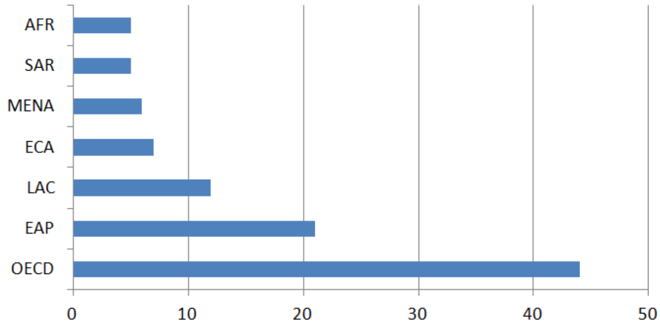


Fig 3 Statistics on waste generation by each region

Solid waste management contributes less than 5% of global greenhouse gas (GHG) emission (Bogner et al., 2007). In response to growing concerns about the threat of climate change, international action aimed at reducing greenhouse gas (GHG) emissions is accelerating and the solid waste management sector is expected to contribute (Turner et al., 2015).

Further recycling of the PSW is limited to some no. of recycling cycles as after recycling product loses some of its properties like strength, stability etc. After a limited no. of recycling PSW only way to dispose off is land filling. But land filling leads to contamination of earth's surface. Further, land filling leads to emission of carbon dioxide gas. Plastic also contributes towards the health related issues like Skin corrosion/irritation, Aspiration hazard, serious eye damage/eye irritation etc. (Lithner et al., 2011). It takes much time for polymerization reactions to complete and, therefore, un-reacted residual monomers often found in the polymeric material, many of which are hazardous to human health and the environment (Matlack, 2001; Araújo et al., 2002).

3. Commercial Polymers

As there are various polymers/plastic based materials are available in the market or as waste. Two basic categories of plastic are designated as thermosetting (long strands) and thermoplastic (short link) materials. Thermosetting plastic materials are those which cannot be recycled again and thermoplastic are those which have certain recycling capacity. This review only focuses on thermoplastic materials. The 6 main families of plastics are: Low Density Polyethylene (LDPE), High Density Polyethylene (HDPE), Polypropylenes (PP), Polystyrene (PS), Polyethylene Terephthalate (PET) and Polyvinyl chloride (PVC). Numbers of plastic are listed in Table 1 for better understanding.

Table 1. Different available plastic polymers and their application (Yu et al., 2016)

Thermoplastic	**Application**	**Thermosetting**	**Applications**
PVC (Polyvinyl chloride)	Construction, Medical, Electrical, Automobile, Packaging, Clothing etc.	Bakelite	Electrical systems, non-conducting parts of telephones, radios and other electrical devices, including bases and sockets for light bulbs and electron tubes, supports for any type of electrical components, automobile distributor caps, insulators, billiard balls
PLA (Polylactic acid)	Decomposable Packaging Material, Cups And Bags, Upholstery, Disposable Garments, Awnings, Feminine Hygiene Products, And Diapers.	Epoxy	Coatings, adhesives and composite materials
ABS (acrylonitrile butadiene styrene)	Drain-waste-vent (DWV) pipe systems, musical instruments (recorders, plastic clarinets, and piano movements), golf club head), automotive trim components.	Melamine	Formica, melamine dinnerware, laminate flooring, and dry erase boards
Polystyrene	Disposable Plastic Cutlery And Dinnerware, CD Cases, Smoke Detector Housings, License Plate Frames	Polyester	Staple fiber (PSF), Bottles for CSD, water, beer, juice, detergents, Technical yarn and tire cord
Polycarbonate	Electrical And Telecommunications Hardware	Polyurethane	Building insulation, Refrigerators and freezers, Furniture and bedding, Footwear, Automotive. Coatings and adhesives.
PET (poly ethylene terephthalate)	Packaging film, PET Bottle, Carpet yarn, Engineering plastic, Filaments, Non-woven, Packaging stripes, Staple fibre.	Urea – Formaldehyde	Wall cavity filler, agriculture, decorative laminates, textiles, paper, foundry sand moulds, wrinkle resistant fabrics, cotton blends, rayon, corduroy, etc.
Polyamides	Tire, cords, rope, thread, brushes, bearings, gears, cams, hot melt or solution.	Faturan	Umbrellas and Parasols, Prayer Beads etc.
Polypropylene	Bi axially oriented polypropylene (BOPP), clear bags, carpets, rugs and mats	silicon	Sealants, adhesives, lubricants, medicine, cooking utensils, and thermal and electrical insulation, silicone grease etc.

10. LDPE(low density polyethylene)	Packaging for computer hardware, such as hard disk drives, screen cards, and optical disc drives, Trays and general purpose containers.	Vinyl ester	Marine industry, FRP(fibreglass reinforced plastics) tanks and vessels, laminating process, Glasair and Glastar kit planes etc.
11. HDPE(high density polyethylene)	Toys, utensils, films, bottles, pipe and processing equipment. Wire and cable insulations	Phenol formaldehyde resin	Billiard balls, laboratory countertops, coatings and adhesives, circuit boards, fibreglass cloths etc.

Virgin plastics are easily available and manufactured with conventional method, but in terms of energy requirement these plastics are on the verge of elimination of fossil fuels. First, plastics can be regarded as a form of stored potential energy as each year, producing virgin plastics requires 4% of the world's oil production equivalent to 1.3 billion barrels a year (Kreiger et al., 2015). So, it is always advisable to reuse and recycle the plastic waste. Some of the known and most used plastic is discussed and elaborated in this attempt. **PVC** is a universal polymer which can be processed into a wide variety of short-life or long-life products (Sadat-Shojai and Bakhshandeh, 2010). Among these major types of plastics, the consumption of PVC contributes to 12% of total demand. Global plastics production capacity of PVC was about 61 million tons in 2013 (Yu et al., 2016). Rigid plasticized PVC is commonly used in pipes, window framing, floor coverings, roofing sheets, and cables; thereby it is discarded at a high rate (Janajreh et al., 2015). **HDPE** is a better material than the LDPE; it is most widely used material. It takes 1.75 kg of petroleum to make 1 kg of HDPE. It is commonly recycled material. Earlier, there was a major recycling of LDPE (low density polyethylene) but it takes high energy requirement of making LDPE as compare to HDPE (Hamad et al., 2013). Another form of HDPE is available, called rHDPE (recycled HDPE), HDPEi completely came from industrial waste (Lu and Oza, 2013) and is easily available from post consumer based products (bags, glass, cups, bottles) (Achilias et al.,2009). It is basically composed of carbon and hydrogen atoms joined to form a high molecular weight product (Hamad et al., 2013). Being linear chain material it has higher strength than LDPE. HDPE is used for various industrial applications (because of good mechanical properties) and emerging as a potential structural matrix (Jaggi et al., 2014). Most of researchers dealt with the HDPE as it is easy to recycle and contribution of HDPE in home products or commodities is maximum amongst others. So post consumer based waste plastic is HDPE based. **LDPE** is very less used polymer in these days because of its manufacturing requirement and other properties constraint. Low-density polyethylene requires extremely high pressures. This high-pressure polymerization creates polyethylene with many branches; the branches are created due to intermolecular and intra molecular chain transfer during polymerization. The utility of low-density polyethylene is limited due to the high number of branches leading to poor strength properties and requirement of extreme pressure condition for its production (Kumar et al. 2011). The structure of this LDPE is less crystalline as compare to HDPE with little or no branching (Hamad et al., 2013). **PET:-** Plastic bottles are usually made up of PET (Assocham, 2015). Use of plastics as bottles is increasing throughout the world (Kalantar et. al., 2012). But recycling of materials based on PET is often very complex and it requires heavy machinery and high investment, so most of the recycler is not interested in recycling of plastic materials based on PET.

4. Identification/Separation of Polymers

Recycling of plastic majorly depends on the type of plastic. Collection of waste does not ensure the type of plastic. Before recycling compatibility issue has to be resolved. In a collection there may be number of plastics. Segregation of plastic has to be done to sort out various materials. Introduction of one polymer into another may lead to reduction in properties of recycled material because of the different melting points (Carvalho et al., 2010). For example blending of PP in HDPE increases the brittleness of HDPE (Sanchez-Soto et al. 2008). Some of the techniques for segregation and identification of different plastic materials is shown in Table 2.

Table 2 Different available plastic polymers separation techniques and their principle

Technique	**Principle**
Laser-induced breakdown spectroscopy (LIBS)	Identification by spectral analysis
Tribo electric separation,	Identification by surface charge transfer phenomena
X-ray fluorescence	Uses X-rays as source
FT-IR (Fourier transformed infrared technique)	By comparing the spectra of waste samples to that of different model polymers
Froth flotation method	Separation by density of material
Magnetic density separation	Based on the differences in density of the materials
The hyper spectral imaging (HSI) technology	By analysing spectra of an image

4.1 Laser introduced break down spectroscopy: - Laser induced breakdown spectroscopy (LIBS) is a relatively new analytical technique based on pulsed laser sources (Pasquini, 2006)**.** It is used for identification of various kind of plastic waste. The capability of this technique is demonstrated by the analysis of the major constituent's carbon and hydrogen present in polymer matrices (Gondal and Siddiqui, 2007). A laser-produced plasma emission is recorded for spectral analysis of various kinds of plastics in order to fingerprint these plastics. Mainly 6 number of plastic materials (Low Density Polyethylene (LDPE), High Density Polyethylene (HDPE), Polypropylenes (PP), Polystyrene (PS), Polyethylene Terephthalate (PET) and Polyvinyl chloride (PVC)). can be identified by this technique. Calibration is done by striking laser beam of Nd:YAG laser of specific wavelength on to the some previously identified plastic waste material (Gondal and Siddique, 2007). The basic representation of the setup of LIBS process is shown in Fig 4.

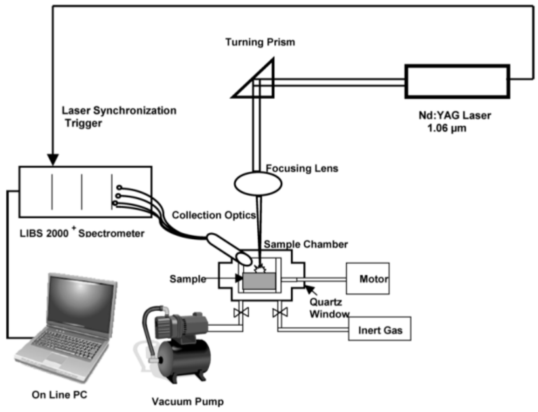


Fig 4 Schematic of the LIBS experimental setup applied for the analysis of plastic samples, Gondal and Siddique (2007).

This procedure is followed for all the PSW materials which are to be identified. The key to profitable recycling lies in the reliable and efficient identification and classification of plastics. Based on identification of the plastics, one can then decide more accurately about the separation technology as the value of recycled materials depends on the fraction purity (Gondal and Siddique, 2007).

4.2 Tribo-electric separation: - Electrostatic separation is a term given to a significant class of technology of modern waste handling, broadly utilized for the sorting of granular blends because of electric forces following up on particles whose normal size is around 5 mm (Tilmatine et al., 2009). Among the separation techniques used in industry, the Tribo electric separation of insulating particles using rotary tube is an efficient technology employed in waste recovery and mineral industries. A tribo electric based separation device sort's materials on the basis of a surface charge transfer phenomenon (Maio et al., 2010). The Tribo- cyclone is a device that utilizes the centrifugal force to charge the particles due to their acceleration and friction against its inner lining (named as charging surface) (Dodbiba et al., 2005). This process, also called free-fall Tribo electric separation, is widely used for the sorting and the purification of granular materials resulting from industrial plastic wastes (Bendimerad et al., 2009).

Further there are two types of tribo electric separation techniques. One is Roll type corona-electrostatic separator used for separation of plastic materials mixed with some metallic parts (Tilmatine et al. 2003). Another is Plate-type electrostatic separator which is used for separation of a mixture of metallic parts (Bendimerad et al. 2009). Fig 5 represents working of Tribo electric separator.

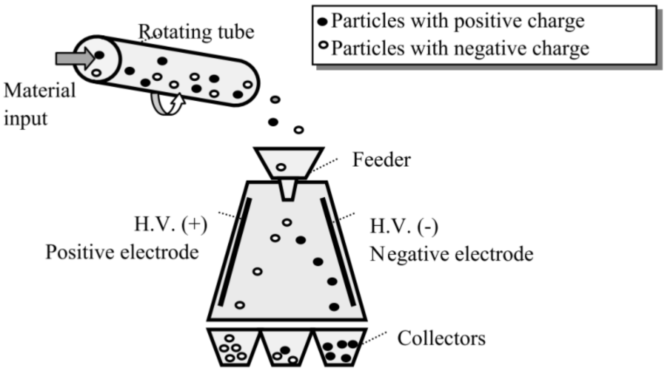


Fig 5 Schematic representation of the Tribo electric separation, Bendimerad et al., (2009)

In this tribo electric separator when two materials are fed and rotated at some speed, then material present inside experience two types of forces, one is particle/particle forces and another one is particle/ cylinder wall force. When two materials rubbed against each other then charge starts appearing on material particles. One gets positive charge and second one achieves negative charge. Then Separation is initiated by forces acting in between them when a material particle passes through the intense electrostatic field. For example, if the PVC is rubbed with Teflon, this latter gets a negative charge and the PVC acquires a positive charge (Bendimerad et al. 2009). In this type of separation technique nearly all plastic material can be sorted out. However, this technique has a limitation of maximum separation of material with a particle size of 2-4 mm (Xiao et al., 1999).

4.3 X-Ray Fluorescence

Another technique, also called XRF spectroscopy identifies different flame-retardants (FRs materials (Maio et al., 2010). Moreover, it is a technique use to determine the chemical composition of all kinds of materials, covers a very wide range, like metal, cements, oil, polymer, plastic and food industry comes under non destructive testing. Very high accuracy can be expected by this technique if good standard specimens are available. Time for measurement of particles depends on the number of elements to be determined and varies from second to 30 minutes. This technique uses x-rays produced by a source, then irradiating a sample with it. Most of cases use x-ray tubes, but sometimes synchrotron or radioactive material is also used. The element which is under inspection will produce fluorescent X-ray radiation with discrete energies (equivalent to colours in optical light) that are characterised for these elements. Different colour signifies a different energy level. By measuring the colours emitted by elements, it is possible to determine the element. This is qualitative analysis. Quantity of an element can also be judged by Intensity of colour.

4.4 FT-IR (Fourier Transformed Infrared Technique)

FT-IR is used for identification of different types of polymers and plastic material by comparing the spectra of waste samples to that of different model polymers. It is used to obtain an infrared spectrum of emission or absorption of a solid, liquid or gas. A FTIR spectrometer simultaneously collects high spectral resolution data over a wide spectral range. This confers a significant advantage over a dispersive spectrometer which measures intensity over a narrow range of wavelengths at a time. FTIR spectroscopy is also used to examine the structural variations as a function of strain (Lanceros-Me ´ndez et al., 2001). Previously FTIR spectroscopy was used to examine the structural variations as a function of strain (Lanceros-Me ´ndez et al., 2001). This technology is now a day's also used for analysing the structural change during the recycling of polymers Achilias et al., (2009). Carvalho et al., (2010) uses this technique for separation of PET, PVS and PS and found very impressive results in separation of plastic by recovering 83 of the PET.

4.4 Froth Flotation Method

Froth flotation is another polymer separation technique used to identify the different plastic polymers. Alter, 1978 was first to recommend that plastic recovery is possible by froth flotation by depending on their critical surface tension. Some authors have found problem of plastic waste accumulation in large quantity (Alter, 2005). Whereas many other separation techniques are available, but froth flotation is one of the simplest and lowest cost methods. This is also used in mineral, processing industry (Burat et al., 2009). Some researchers have applied froth flotation to separate post-consumer PET (Polyethylene Terephthalate) from other packaging plastics with similar density (Carvalho et al.2010). Takoungsakdakun and Pongstabodee,(2007) and Marques et al. (2000) used this technique for separation of PVC, PET, and POM. The flotation was initially developed for ore separation around a century ago (Fraunholcz.2004). By using this technique 95-100% of PVC or PET can be separated (Drelich et al., 1998). Because of the hydrophobic nature of the all plastic/ polymer material, froth flotation is a little bit challenging as air bubbles presence in material make material to float. Since hydro-phobicity and gravitational force related to mass both are responsible for flotation of material, (Pascoe and O'Connell, 2003). Separation of plastic of generic types is however possible, but LDPE and HDPE are not separable by this technique (Alter.2005). Fraunholcz (1997) and Shen et al. (1999, 2001, 2002) done a lot of experimental work on separation of plastic by froth flotation but experimentation on MSW was not reported on a large scale.

In this experimentation wetting agent and frothing agents are necessary for recovery of plastics. Calcium lignin sultanate as a wetting agent and pine oil and MIBC (methyl isobutyl carbinol) as a frothing agent is used. When pine oil is used as frothing agent recovery of PVC becomes better, while MIBC give results in favour of PET recovery. Over all Froth flotation found major and efficient separation method in mineral processing engineering and useful for mixed plastics separation, (Barlaz et al., 1993). Fig 6 represents the basic representation of froth flotation process.

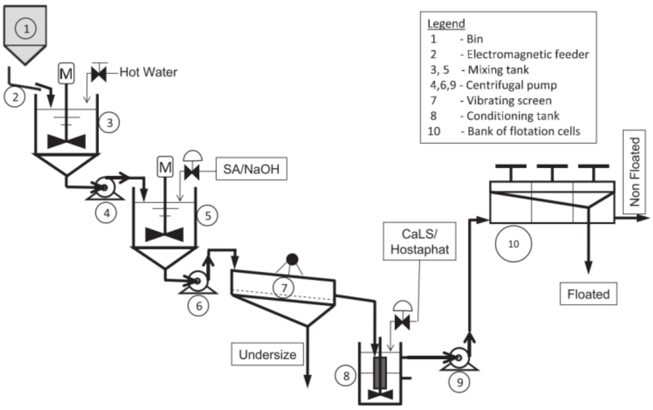


Fig. 6. Basic Process involves in froth flotation method Carvalho et al., (2010)

The material which is to be separated is firstly fed into the first tank, then with the help of an electro- magnetic feeder, where they mixed with hot water. Mean residence time in this tank will depend on time of proper mixing and complete contact of particles with water before caustic/alkaline treatment. The alkaline treatment is carried out in another container. Again for mixing mean residence time has to be selected. After this pulp formation will take place and fed into vibrating screen for rinsing with cold water. Wetted material and cold water are then fed into a tank where the surfactants are present for chemical treatment. Residence times are dependent on the type of alkali and chemical used for conditioning. The pH of alkali liquid should remain constant. The temperature of the water used for alkali treatment is very important and plays a major role. Because some time it is not possible to attain high temperatures due to absence of proper water heating systems. Samples of different product streams may then be separated and extracted at predefined time intervals for analysis and approximation of the product weight. Plant for this treatment cover a huge space and cleaning and washing of material, thus become a tedious role. Washing plants should be designed in such a way that every part may be easily reached and cleaned, even if it will require a greater space for the plant installation (Perrone, 1988).

4.5Magnetic Density Separation

In order to achieve production of high purity material from complex streams of post consumer waste of quality comparable to materials being produced by post industrial waste a separation technology is necessary that can sense very small changes in physical properties . This technology can be helpful in separation of useful plastic from waste at minimized residue material (Maio et al., 2010). This technology primarily works on identification of primary plastic contained in particular waste content after manual sorting (Al-Salem et al., 2009). MDS is a physical separation method based on the differences in density of the materials (Murariu et al., 2005). In this optical sensing technique can be applies, but some time it is not successful because of the size of the plastic material present. Other methods in this is separation by density. By this technique electronic waste can be separated (Kang and Schoenung. 2005)by adding a modifier in water, but it may lead to contamination of recovered plastic (Veit et al.,2002). It is used to separate the various types of polypropylene (PP), low density polyethylene (LDPE) and high density polyethylene (HDPE), from each other and from contaminated materials such as wood, rubbers and minor amounts of metals. MDS is potentially very cheap because it separates a complex mixture into many different materials in a single step, using the same liquid. The entire process is performed as the mixture flows through a channel and separation occurs in seconds into different layers (Maio et al., 2010). Fig 7 represents the layout of MDS setup.

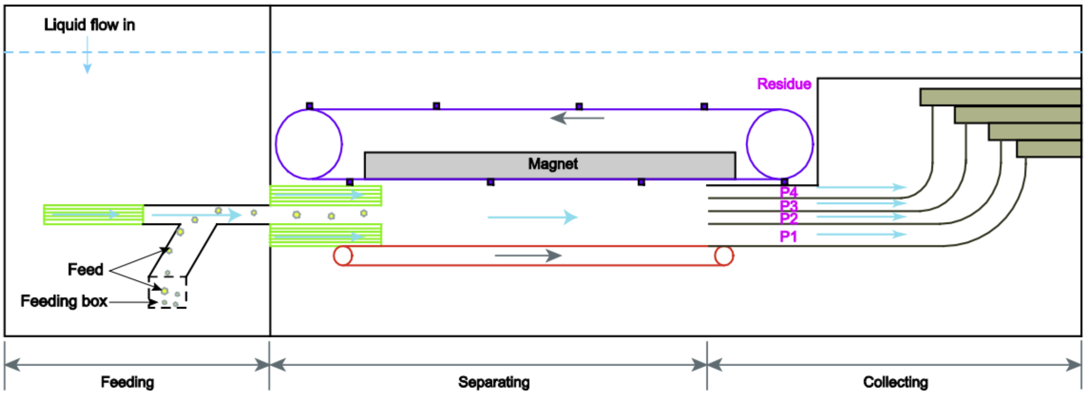


Fig 7 Schematic of magnetic density separator Serranti et al. (2014)

The MDS setup has four steps: (i) Wetting, (ii) Feeding, (iii) Separating and (iv) Collecting. Components of the MDS setup are submerged in the liquid surface. In this process liquid used is magnetic in nature which circulate in whole setup and moves from left to the right side under the influence of pressure difference and then flows back again. The materials are firstly wetted with boiling water for a minute as to make the surface hydrophilic (Hu et al., 2010) and to remove heavy plastics. The wetted particles are fed into a stainless steel box with openings of 1mm. In order to avoid air caused turbulence in the system, Air in the feeding box is first discharged before the placement of box in position. When the lid of the box is open, the particles start rising up and then starts flowing into the separation channel with the mainstream, here density of material lays a major role. In general, a plastic flake of thickness 1mm takes three seconds to reach their equilibrium height in MDS (Bakker et al., 2009; Hu, 2014), so the speed of the flow speed in the separation channel has to be optimized. At the end of the separator, there is the fitment of splitter for output; here in Fig 5 P1, P2, P3, P4 shows the various layers of separated plastics.

4.6 The hyper spectral imaging (HSI) technology

Introduction of hyper spectral imaging **(**HSI) (Bonifazi and Serranti, 2006) analysis was to check and introduced in the recycling process to observe the quality of two separated product streams (PP and PE). Fast and non-destructive nature of this technique can be also utilized for the analysis of particulate solid systems in terms of composition and spatial distribution, including different fields as in food and pharmaceutical sectors (Serranti et al., 2015). This technology was originally developed for remote sensing applications (Goetz et al., 1985) but later it found application in the field of astronomy (Hege et al., 2003, Wood et al., 2002), agriculture (Monteiro et al., 2007,smail et al., 2006, Uno et al., 2005), pharmaceuticals (Lyon et al., 2002, Rodionova et al., 2005, roggo et al., 2005), medicine (Ferris et al., 2001, kellicut et al., 2004, Zheng et al., 2004, Gowen et al., 2007), recycling sector (Serranti and Bonifazi., 2007) for various waste materials (Bonifazi and Serranti., 2006a, Bonifazi and Serranti., 2006b), compost product quality control (Dall'Ara et al., 2012), characterization of end-of life mobile phones (Palmieri et al., 2014) and characterization of different plastics (Serranti et al., 2011, 2012; Ulrici et al., 2013; Luciani et al., 2013). Basic of HSI is the use of an integrated system consisting hardware and software which enable it to digitally capture and analysing spectra as an image sequence. Each sample can be analysed on the basis of different physical –chemical characteristics, according to the different wavelength of the source and spectral sensitivity of system. Fig 8 shows the basic structure of HSI imaging.

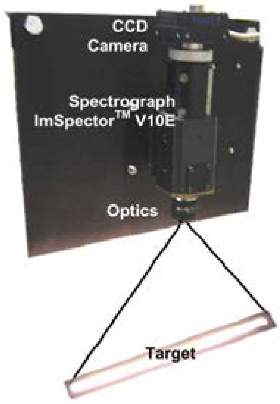


Fig.8. Hyper spectral Imaging (HSI) based acquisition device to collect secondary plastic particle flow streams spectra.

The basic system of HSI operates in some definite spectral range with some resolution. Images are acquired with the help of system having some definite pixel density. The spectrograph is constituted by optics based on the volume type holographic transmission grating. The grating is used in patented prism-grating-prism construction (PGP element) characterized by high diffraction efficiency, good spectral linearity and it is nearly free of geometrical aberrations due to the on-axis operation principle. A light beam is made to fall on PGP so that central wavelength passes symmetrically through the PGP and short and longer wavelength are dispersed up and down compared to central wavelength. This results in minimum deviation from on axis condition along with a digital image. In image spectral columns represents a discrete value of the corresponding element of sensitive linear array. Form this digital image each element can be sorted out by analysing the different values of the generated spectra with the help of detection device (Maio et al., 2010).

Furthermore, there are many other techniques which are being used for identification of polymers Like, Differential scanning calorie meter (DSC) (Frick and Rochman, 2004), Speed accelerator technique (Al-Salem et al., 2010), Eddy current technique ((Cui and Forssberg, 2003), Chemical identification, Electric conductivity-based separation (Xue et al., 2011), Corona electrostatic separation (Bendimerad et al., 2009), Near infra-red (NIR) (Rigamonti et al., 2014) and Gravity separation (Shent et al., 1999) are available. DSC is basically used for quality control and thermal analysing technique (Giron and Goldbronn, 1997). By providing information about the changes in the crystalline fraction, DSC data allowed measurement of the melting temperatures and enthalpies of the material before and after deformation. By differential scanning Calorimetry (DSC) some endothermic behavior can be observed by means of the disordering of crystallites (Frick and Rochman, 2004). The specimen is put in an aluminium crucible and closed by pressing aluminium cap, which is pierced by a needle on the top for degassing. The sample is heated once over the defined temperature range. The sample starts degrading by heating up to 300 °C which could be recognized visually after measurement. The colour of the sample clearly changed and the melt flow starts easily. By heating, the sample starts melting without colour changing and became spherical if the material is viscous at that temperature. After that graphs are generated by machine and can be analysed accordingly. Speed accelerator is a technique used for plastic separation developed by Result Technology AG (Switzerland). It uses high speed accelerator to delaminate waste and that delaminate waste is separated by air classification, electrostatics and sieves (Kang and Schoenung. 2005). The Eddy current separators utilized in various non-ferrous metals sorting and recovery operations, most common is the sorting of non-ferrous metals from shredded automobile scrap and municipal solid waste (Dalmijn and Houwelingen, 1995, Rousseau and Melin, 1989, Rem , 1999). Further, in the recycling of Waste electric and electronic equipment, the use of the traditional Eddy current separator is limited, due to the size of feed required. Particles greater than 5mm in size or, even 10mm are needed (Zhang and Rem,1999) This technique is also employed in separation of plastic particles from a metal/plastic mixture (Zhang et al., 1999, Schlett et al., 2002). The chemical identification of plastics waste is a slow process involving considerable instrumentation, such as spectroscopy, thermo gravimetric, differential thermal analysis, mass spectrometry, pyrolysis-gas chromatography and selective dissolution (Buekens, 1977). Some of them are elaborated in the above sections. In these techniques, materials are judged on the basis of their chemical behavior upon heating and exposure to radiations.

5. Various Recycling Techniques

There are four main approaches for recycling of PSW; as primary, secondary, tertiary and quaternary recycling (as per ASTMD, 2000), see Fig9.

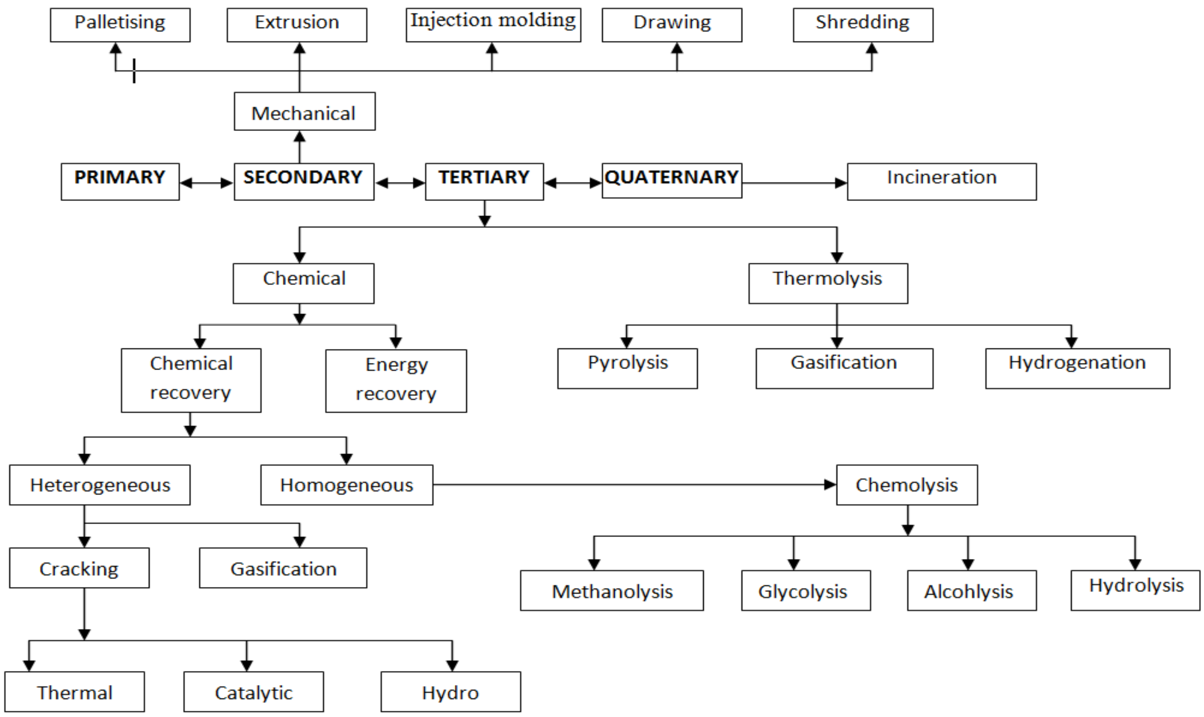


Fig.9 Various approaches for recycling of PSW

Recycling technique of polymer does play an important role in the generation of new polymer. Every technique has its own advantages and disadvantages. When material undergoes a recycling process it starts losing some of properties in terms of tensile strength, wear properties and dimensional accuracy. Further some of the recycling techniques are elaborated below.

5.1 Primary recycling

Primary recycling better known as re-extrusion (Al-Salem, 2009) or closed loop process (Sadat-Shojai and Bakhshandeh, 2011) is recycling of uncontaminated, single type of polymer having properties near to virgin material (Kumar et al. 2011). This process utilizes scrap plastics that have similar features to the original products (Al-Salem, 2009). It can only be done with clean or semiclean scrap after successfully sorting out the contaminated parts. Usually MSW is not suitable for primary recycling due to excess contamination (Yu et al., 2016).

Some time to obtain better properties in comparison with virgin material, introduction of clean scrap is made into collected waste (Kumar et al., 2011). This technique is easy to use and popular in manufacturers, because of conversion of plastic waste into original quality product (Sadat-Shojai and Bakhshandeh, 2011). More or less it includes injection moulding and other mechanical recycling techniques; difference is about the quality of material (Barlow, 2008).

5.2 Secondary Recycling

Primary and secondary recycling techniques are well established and widely applied techniques (Al-Salem, 2011). Although both of these are linked to mechanical recycling of plastic and used for recycling of PSW by mechanical means (Mastellone, 1999). Secondary recycling is transformation of material by mechanical mean for less demanding products (Kumar et al., 2011). The steps involved in secondary recycling are usually (Aznar et al., 2006; SubsTech, 2006): Cutting/shredding, Contaminant separation, flakes separation by Floating. After these steps single polymer plastic material is processed and milled together to form granulated form. Then pre washing followed by drying is done to remove all kinds of glue particles. Some time chemical washing by using caustic soda is done for glue removal. Then the product is collected, stored and sold after addition of pigments and additives.

Further extrusion of plastic strands is done by making pallets according to requirement and then final products are made (Al-Salem et al., 2009). Kumar et al., 2011 described two approaches for recycling of polymer waste. The first one being separation of plastic from their contaminants and segregating it into generic form further recycling it into products produced from virgin material. Another approach is after separation from contaminants and re-melting it without segregation. Secondary recycling includes various methods of recycling (like screw extrusion, injection moulding, blow moulding etc.). One such method namely screw extrusion is discussed as under:-

5.2.1 Screw Extrusion

Extrusion methods are widely used for the processing of polymers and composites containing them, agricultural raw materials, food, waste, meat, and leather, as well as other raw materials (Mikulionok and Radchenko, 2012). Now a day’s single and twin screw extruder are available for the recycling of processing of the materials. But both have their different process parameters. Single-screw and twin-screw has some differences and benefits depending on the plastic being processed (Hopewell et al., 2009) .Various varieties of extruders according to sizes, shapes and methods of operations are available (Frame, 1994). In polymer processing technology screw extrusion is the most important operation (Covas and Gaspar-Cunha, 2001). Plastic extrusion is a process in which the material having some polymer chain can be altered by heating up to its melting point. In this, the material is put into barrel and then heated up to a specific level and forced to move through some die that is having required dimensions, after which material comes out of the die as per die shape. Most commonly, plastically extruded materials are in cylindrical shape. To maintain the uniformity of extruded material, some arrangements are made to preheat the material (Al-Salem et al. 2010). Time of cooling and speed of rolling of the material play a major role in dimensional accuracy and properties of the wire being extruded (Wang et al., 2011). Most of the plastic materials are available in powder shape or granules. They are processed at room temp. The plastic extrusion machine melts the material and homogenizes it before entering into the die. Conversion from cold to hot state accounts some energy. The shape of the material depends on many factors which include pressure, flow rate of material (MFI), orifice shape, and cross section of extruded and most important the rheological properties of the material. MFI determination is the standard test for getting rheological property of polymer (Navratil et al., 2015) The ratio of the channel depth in the feed section to the channel depth in the metering section is often referred to as the compression ratio of the screw. For having effective pumping action the volume of feed should be 2 or 3 times the volume at the front and this ratio of volume is called the compression ratio (Campbell and Spalding, 2013).

Mainly, this machine has following listed parts (see Fig10):

- Hopper
- Cylindrical barrel
- Screw
- Die head
- Motor for running of the screw

Different types of materials are available in the market in powder form and granule form. The material into barrel through hopper under the gravity action. The cylindrical barrel is surrounded by the heaters that can be controlled manually with a set of specific temp range. Generally, the temp range of normal screw extruder is up to 275 degree Celsius, which is enough to melt thermoplastic materials. As material enters into the barrel, the material starts heating up. The screw starts leading the material in the forward direction towards the die. The length of barrel plays a major role. The role of screw speed is also important. If the screw is having more speed then the material will not melt properly, as the material will lead at faster speed. And if the speed of screw is low, then material will be over melted and the wire will not form properly. Melting temperature being an important parameter plays a major role in the flow properties of polymers (Sombatsompop and Panapoy, 2000). The screw pushes the material positively into the barrel and lead it to the die. There can be multiple heating zones. Those heating zones gradually increase the temp of the material. The pressure, which screw is exerting on the material may reach to 5000 psi (34 MPa). Then material reaches to the breaker plate that create back pressure. This is required for uniform mixing and uniform melting of material. After passing through the breaker plate, material comes to the die and starts passing through it and thus wire is formed

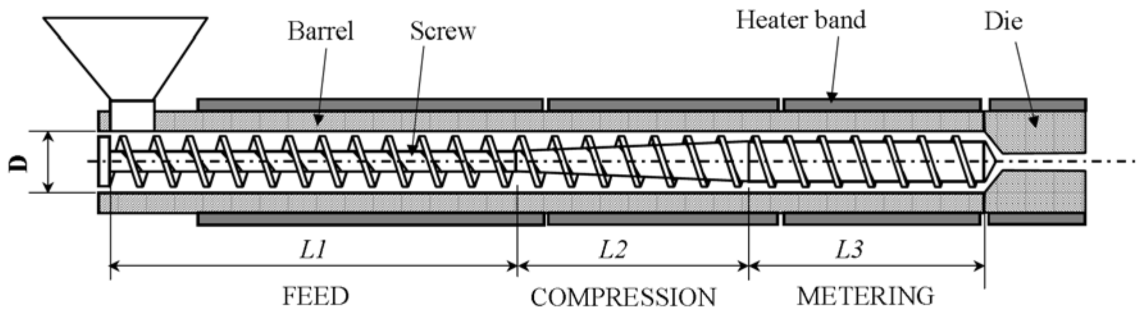


Fig.10 Schematic of single screw extruder Covas and Gaspar-Cunha (2001)

5.3 Tertiary recycling

Primary and secondary recycling techniques are some time appears difficult to process, since it includes identification and sorting of material by various methods. In primary recycling un-contamination of polymer waste is a difficult task because most of the MSW is a collection of heterogeneous components. Specially in secondary recycling the in homogeneity of municipal solid waste makes it very difficult to be recycled (Sadat-Shojai and Bakhshandeh, 2011).

It is a known fact that polymer is made up of petroleum based products (Kumar et al. 2011). Primary and secondary both techniques do not contribute towards the principle of energy sustainability. On the other hand, of tertiary recycling proves its contribution towards the principle of energy sustainability (Yu et al. 2015). Because it leads to the generation of the raw materials from which the plastics are originally made, therefore attaining attention of recyclers. It involves various Methods of recycling including pyrolysis, cracking, gasification and chemolysis. Basically recovery of monomers from PSW from depolymerisation process is called tertiary recycling. Chemical and thermal recycling are the major types of tertiary recycling techniques available. Depolymerisation of PSW by chemical means and heat is called solvolysis and thermolysis respectively. Further process is called pyrolysis if done in the absence of air. If done in controlled environments then it is called gasification. The degradation of polymers in the presence of glycol like diethylene or glycol ethylene glycol is known as glycolysis and the degradation of polymers in the presence of methanol is known as methanolysis and this is also an example of transesterification (Kumar et al., 2011).

5.4 Quaternary Recycling

After a number of recycling cycles of PSW by primary, secondary and tertiary techniques material starts losing its properties. The only way to discard the waste is to land fill. But land filling of material leads to contamination of earth's surface. The more effective ways of disposal of waste goes through quaternary recycling of material or waste. MSW disposal by combustion is increasing due to increase in efficiency of new incinerators (Subramanian, 2006). In quaternary recycling waste material is processed to recover energy through incineration. It also leads to volume reduction of waste and rest can be land filled (Kumar et al. 2011).

Table 3 Calorific values of various available polymers (Al-Salem et al., 2010).

Item	Calorific value (MJ kg^{-1})
Polyethylene	43.3-46.5
Polypropylene	46.50
Polystyrene	41.90
Kerosene	46.50
Gas oil	45.20
Heavy oil	42.20
Petroleum	42.3
Household PSW mixture	31.8

Recycling of plastic waste by the energy recovery method is logical only when recycling of waste is not possible due to constraints (Al-Salem et al. 2009). As it is well known that plastic materials are derived from crude oil and they posses' very high calorific value (Dirks, 1996). Table 3 demonstrates the calorific value for different plastic polymers as compare to oil and petroleum. A number of environmental concerns are associated with co- incinerating PSW, mainly emission of certain air pollutants such as CO2, NOx and SOx. The combustion of the PSW is also known to generate volatile organic compounds (VOCs), smoke (particulate matter), particulate-bound heavy metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated dibenzofurans (PCDFs) and dioxins (Al-Salem et al. 2009). While combustion, emission of harmful and environmental polluting gases is major issue involved. That can be controlled by different methods, (i) activated carbon addition, (ii) flue gas cooling, (iii) acid neutralization, (iv) ammonia addition to the combustion chamber and/or (v) filtration (Yassin et al., 2005).

6 Reinforcement in Recycled Material

Plastics and polymer-based composites have become superior structural materials in engineering practice. The use of virgin material is getting less attention in product preparation because of lack of the required properties, however, recycling of virgin plastic /polymer is relatively easier rather than reinforced material (Yildirir et al 2015). So more attention is inclined towards the reinforced materials so as to achieve the requirement of Taylor made properties. Many examples of reinforcements like sisal, coconut fiber (coir), jute, palm, bamboo, rice husk, wood, paper, strands of glass fibre, CaCO3, asbestos, mica, natural fibres) in thermoset and thermoplastic are present in literature (Herrera-Franco et al, 1997, Guedes et al., 2016). Before blending of filler in parent material is bonding of both the present particle is much needed. For this selection of compatibilizer or a bonding agent is necessary. Like Bonding between the polymer and rice husk can be improved by proper selection of compatibilizer or coupling agents (Kumar et al., 2010). Many authors recommend different reinforcing materials stating their respective advantages and disadvantage. (Adhikary et al. 2008) used Pinus radiate wood fibre in experimentation and found it suitable for reinforcing in plastic material. Many studies found an improvement in mechanical properties and dimensional stability by reinforcing wood fibre in plastic (Adhikary et al. 2008). Singh and Singh, 2015 used Al and Al_2O_3 powder particles as reinforcements in nylon 6 matrix and found improved results. Work has also been proposed on using plastic bottles as reinforcement in stone mastic asphalt (Ahmadinia et al., 2011). Further reinforcements in shapes of fibres are also in trend. Most commonly carbon and glass fibres are used as reinforcements; mainly in the manufacturing of carbon fibre reinforced plastics (CFRP) and glass fibre reinforced plastics (GFRP) (Onwudili et al., 2016). Also, some studies have reported the use of carbon fibre (CF), glass fibres, wood flour, sand, natural fibres, aluminium powder, aluminium oxide, carbon nano tubes as reinforcements (Herrera-franco et al.,1997, Adhikary et al. 2008, Lu and Oza, 2013, Jen and Huang, 2014, Oliveux et al. 2015, Yaldiri et al., 2015) for improvement in properties. Natural fibres are comparatively inexpensive, but have relatively low tensile strength and modulli (Jayaraman and Halliwell,2009). Natural fibre composite products made from waste-based materials offer great potential for waste management as well as poverty reduction, especially in developing communities where waste scavenging is common (Baillie et al., 2011).Composites made of natural fibres completely biodegradable and are called ‘‘green composites’’ because of their environment friendly properties (Kumar et. al., 2015). The effectiveness of reinforcement of composites with fibres highly depends on the ratio between their length and diameter (l/d), because there is effect of the ratio on the strength of the composites (Nestore et al., 2013). Gu and Ozbakkaloglu, 2016 used recycled plastic waste in concrete mix to enhance its properties and observed improvement in mechanical properties including compressive strength, splitting tensile strength, flexural strength, elastic modulus etc.

A series of comparative studies have shown that of recycled PET fibres with high tensile strength appear to be the most beneficial in terms of compressive and tensile properties in the case low-strength cement-based concretes with high water/cement ratio (0.53), while, on the contrary, fibres with crimped aspect and relatively low tensile strength appear to be the most beneficial in terms of compressive strength and first-crack strength of high-strength cement-based concretes with low water/ cement ratio (0.38) (Fraternali et al., 2011, 2013; Spadea et al., 2014). Similarly, recycled PET and nylon fibres showed to me most effective in the reinforcement of low-strength cement mortars than high-strength cement mortars (Fraternali et al., 2013; Spadea et al. 2015). Overall, available literature results highlight that the addition of recycled plastic fibres to cementitious materials needs to be accurately tailored to the employed mixed-design, both for what concerns the choice of the fibre properties, and in relation to the desired strength and ductility properties of the final material. Attention is increasingly being given to the use of recycled plastic materials for the fused deposition modelling (FDM) of innovative reinforcements of cement-based building materials (Singh et al., $2016_{1,2}$; Farina et al., $2016_{1,2}$).

Reinforcement in polymer/plastics are not as easy because of the nature of both materials so there could be use of bonding materials such as silanes or organo-titanes to enhance reinforcements. Adhikary et al., 2008 uses the maleated polypropylene (MAPP) as a bonding agent in plastic material and found a huge increase in stability and mechanical properties while without a bonding agent no improvement in tensile and flexural properties were found. Various researchers used extrusion process for reinforcement of filler in parent material while some used hot mounting machines to make composite (Singh and Singh, 2015, Adhikary et al., 2008).

7. Applications of Recycled Polymers

Recycled Polymer/plastic is highly used in manufacturing industries for the preparation of products. Industries are more interested in cost reduction, hence using recycled material is better choice for cost reduction and also helpful in reducing waste. Polymers are an excellent and a very useful material to replace ceramic, wood and metals because they are very functional, hygienic, light and economical (Burat et al., 2009). One of the very interesting applications of recycled plastic is manufacturing of plastic lumber (timbre). Breslin et al., 1998 used post consumer based plastic (polyolefin) for construction of docks, marine piling, pier and dock surfaces, fences, park benches, Piers and bulkheads and examines the long-term engineering properties of plastic lumber manufactured using post consumer waste plastic. Most of the feedstock used for plastic lumber is composed of polyolefin {high density polyethylene (HDPE), low density polyethylene (LDPE) and polypropylene (PP)} (Nosker and Van Ness, 1998). Previous studies showed the use of plastic lumber in a variety of applications (Nosker et al., 1998, Renfree et al., 1989, Zarillo and Lockert., 1993). Reinforcement of various plastic waste material results in improvement in in-plane compression modulus, dimensional stability and the Shore D surface hardness. Another example of recycled plastic waste is wood, plastic composite (Sommerhuber et al., 2015). Wood is the basic material for furniture, interior decorating, and construction industries (Brostow et al., 2015).

Wood plastic composite (WPC) has got good properties in terms of low moisture absorption, low density, resistance to biological attack, good dimensional stability, and a combination of high specific stiffness and strength (Valente et al., 2011; Zimmermann and Zattera, 2013). WPC tends to be a good intermediate step in the cascade chain of biomass and are recyclable (Migneault et al., 2014; Teuber et al., 2015). Use of recycled plastic in development of renewable energy technologies by recovering and storing the heat is also a new area of research which is being explored. For this recycled HDPE reinforced with graphite is used and a composite has been made by improving thermal properties by optimization of manufacturing processes and varying the composition of a mixture of both HDPE and graphite. Then thermo gravimetric analysis (TGA), DSC, and laser flash analysis (LFA) has been done to assure the improvement in properties because of graphite (Yang et al., 2016). Biodegradability is a limitation of plastic material, but this nature of a plastic can be used in another way preparing those parts which are more prone to environmental conditions and need more life span. (Ávila and Duarte, 2003) used plastic waste in the same manner by recycling various types of plastic material by combining HDPE, PET, LDPE, PP in various compositions. Cylindrical parts were made from that composition and finally spur gears were made for end user application. Different researchers have worked on improvement of various properties of asphalt by incorporating various recycled polymers. Asphalt pavement is any paved road surfaced with combination of approximately 95% stone, sand, or gravel bound together by asphalt cement, a product of crude oil. In a research study Ahmadinia et al., 2011 represented a work by using waste plastic bottles (PET) as additive for stone mastic asphalt and found it effective and convenient way for reduction of cost related to construction of roads. Incorporation of polymer material (PET) in stone mastic asphalt showed significant improvement in mechanical and volumetric properties.

8. Case study of metallic powder reinforcement

As discussed above various researchers have used reinforcements like fibres, sand, wood particles etc. in polymer waste, but reinforcement of metallic/ ceramic is limited. For this a case study has been performed to explore the area of metallic/ceramic reinforcement. In this case study HDPE has been taken as matrix material and Fe powder has been taken as reinforcement.

Initially different proportions of Fe powder as reinforcement in HDPE waste was selected based upon MFI. Fig 11 shows MFI setup used in this study.

Fig 11 Basic MFI setup

After establishing MFI, recycling of waste plastic was performed on single screw extruder machine. Various properties of developed wire from single screw extrude machine has been checked. Fig 12 shows 3D view of single screw extruder machine.

Fig 12 3D view of single screw exruder setup

The present study highlights the composite's MFI based on two different proportions of waste polymer (see Table 4) with metal powder reinforcement which may be used as standard data.

Table 4 MFI (in g/10min) of HDPE with Fe powder reinforcement

Polymer/ Composite	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7
HDPE 100%	1.42	1.41	1.41	1.42	1.42	1.42	1.41
HDPE 90% +10% Fe	2.51	2.48	2.49	2.50	2.51	2.52	2.50

After fixing MFI value, filament wire was prepared on single screw extruder machine and various properties of wire such as peak elongation, strength at peak; strength at break, Shore D hardness has been checked. Table 5 represents the values of various properties of composite materials.

Table 5 Different properties of filament wire.

S.No.	Peak elongation	Peak strength(kN/mm^2)	Break Strength (kN/mm^2)	Shore D hardness
HDPE 100%	2.4	12.98	13.23	52
HDPE 90%+10% Fe powder	3.64	12.63	15.02	52.5

As observed from Table 5, after reinforcement of HDPE with Fe powder the new composite material has improved mechanical properties. The composite wire prepared can be used as a filament for FDM setup for different engineering applications.

9. **Conclusions and directions for future research**

The various issues regarding PSW management, including recycling of material is presented in this paper. Decreasing the use of virgin material and reusing the PSW will contribute towards the sustainability of environmental and global warming situation. Land filling being the easiest option to discard the PSW is continuously increasing the global issues on the other hand increasing the space requirement. To reduce the land filling various technologies along with separation techniques, reinforced plastic material and applications of reinforced PSW have been discussed in this paper. This paper contributes the various separation/ identification techniques for PSW including froth flotation and MDS. Froth flotation method can handle high amounts of PSW separation efficiently in single term and most commonly used. Without separation of plastic material contamination of collected waste can reduce the properties of bi-product. In Asian countries primary and secondary recycling technique is majorly used, but leaving some disadvantage in terms of loses of various properties of PSW being obtained as by-product and consumes a very high amount of energy. Efforts have been made by various researchers to obtain by products of similar properties as of virgin material by various other techniques like tertiary which include chemical treatment of PSW as it includes the recovery of energy from polymer since polymer is a petroleum product in the form of heat. Further incineration also becomes a recycling technique in this PSW is used as fuel because being a petroleum bi-product it has any calorific value which in turn lead to the sustainability of natural resources. Recycling of product with filler material is also becoming an attractive field by reinforcing various fillers in polymer material to enhance the properties. So far sand, fibre, ash, rice husk and wood husk have been used. Further, many areas have to be explored in the field of plastic recycling by reinforcement of metallic/ceramic parts like SiC, aluminium and iron in powder form to enhance the mechanical and tribological properties. An alternate route through a fused deposition machine (FDM) may be put in a light. Reinforcement in PSW can be done by primary and secondary recycling techniques by feeding manually mixed PSW and filler material in various proportions. With this process filament wire could be obtained and fed into FDM setup and various direct applications like rapid tooling can be satisfied with this route.

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