Modification of Polystyrene Based Composites for Environment Sustainability: A Review

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Abstract:

Polystyrene (PS) being a non-biodegradable polymer is brought under application over the world in many ways in our day-to-day life to make it easy however it generates an enormous challenge to the components of our environment viz. soil, water, air etc. thus leading to health issues in humans and other living components of earth. This review details and compares the fabrication, application and suitability of various composites of PS with biodegradable materials viz. starch, bagasse lignin, fibers, etc. as to combat the hazardous impact of PS to environment and its valuable constituents. These biodegradable materials not only modify the PS physically but also it affects the composition which enables these composite materials to be acceptable for consumption without spoiling nature. The numerous compositions are studied for their diverse applications and biodegradability. The listed composites express the route to curtail the impacts of hazardous synthetic polymers from the environment and thus paving the path for secure and harmless future for coming generation.

Keywords: Polystyrene, biodegradable, bio-composites, synthetic polymers

1. Introduction:

In this current era of fabricating synthetic material/polymers for extended sustainability, durability, low cost and easy handling humans had generated variety of synthetic polymers which tries to cover all the materialistic necessity of humankind. These synthetic polymers are not only used for fabricating furniture or daily commodities but are also used for preparation of fibres (for clothes etc.) as well are used for packaging food and
beverages. These various application and properties of these synthetic polymers had brought an ease in human life (Table 1). But this ease of application of synthetic polymers had brought a curse on human ecosystem as these materials are not environment benign as well, they remain in various component of environment for years thus creating a threat for not only humans but for various strata of life. The most affected one are those which come in direct contact of these slow poison, which is present in air, water and soil [1]. PS is one of the most versatile synthetic polymers and finds its application in refrigerator liners, food packaging, vending cups, cousin material during transport of goods etc. Due to human ignorance it is generally not properly discarded and hence get accumulated in different environmental components. This can lead to various hazards viz. hormonal disruption, chronic disorder, fatigue, damage liver and nerve tissue and can be carcinogenic also [2]. Looking into the hazards caused by PS it is important to discard it well or else use it in such way that hazards could be minimized. In this review authors had tried to explain the hazards caused by PS as a synthetic polymer and had summarized the various attempts done by the researchers to minimize the negative impact of PS over environment. This review will lead the reader’s knowledge towards the effective management of PS and its impact.

1.1 Polystyrene polymerization, properties, applications and hazards: Polystyrene (PS):

Polystyrene: IUPAC name poly(1-phenylethane-1,2-diyl) and has a relatively low Tg (373 K (100°C). It is a type of thermoplastic polymer which can be brought into use in solid or foam form [1]. PS, which is a basic need of today’s materialistic world, is prepared by many monomer units of styrene. PS has a huge application in our day-to-day life, the normal things we use like Styrofoam for drinking our tea or coffee and for taking food in the same plate, the packing materials, building docks and watercrafts and used majority for insulating homes, office, etc., [2] is made from the synthetic polymer PS which is not at all degradable in our nature (soil, water, air etc.) it remains as such for 1000’s of years which create environmental pollution [3].

![Polystyrene molecule](image-url)

Fig 1: Polystyrene molecule
It follows free radical mechanism for polymerization [4]:

**Mechanism:**

**Initiation:**

\[
\text{Initiation:} \quad \text{R}^+ \rightarrow \text{R}^* \quad \text{Where,} \quad \cdot \text{represents free radical}
\]

**Propagation:**

\[
\text{Propagation:} \quad \text{R}^* \rightarrow \text{R} \quad \text{Termination:} \quad 2 \text{R}^* \rightarrow \text{R}-\text{R}
\]

**Polymerisation:**

Overall Reaction

\[
\text{styrene} \rightarrow \text{polystyrene}
\]

**1.2. Hazards/ negative effects of PS:** Humans are affected by negative effects of PS due to their lifestyle, hot food in PS plates or hot tea or coffee in plastic cup are very hazardous to us as they are hot, they release styrene from the products. The level of around 350 ng/g is 1/3 of
level known to cause neurotoxic symptoms. Styrene shows its toxicity as neurotoxic by attacking the central and peripheral nervous systems (CNS and PNS) and can also increase the thyroid hormone level [5]. In a similar manner PS is detrimental for floras, as plants can be potted in Styrofoam pots but they do not have any minerals that are required by our plants to grow. They are only useful to not let the water go out but what about minerals. Plants will die after so much of water and lack of minerals and the roots of plants always grows so after some time there will be no space in the pot and the Styrofoam with no drainage will not allow the roots to grow and the plants will die [6]. Environmental components such as soil is damaged a lot by PS, as soil cannot decompose it, it just get degrades into smaller pieces and remains in our environment over 100 to 1 million year depending on the environment. After the use of PS we discard them in the soil as a waste there leaching take place when polystyrene exposed under some heat for long time and after this tiny amount of styrene can seep out of the material and contaminate soil [7]. Similarly burning of PS releases carbon monoxide (CO) and styrene monomers in the environment which can cause extremely hazards to environment. In the product manufacturing process it causes greenhouse gas effect. Extruded polystyrene is made up of hydro chlorofluorocarbon and these agents have a very serious effects on our ozone depletion and global warming [8]. After the use of commodities prepared of PS they are discard away, left out food in them can be consumed by the animals and along with the food they eat the plastic also which cause choking and kill them. When animals like cow, buffalo, goat, etc., eat them they might survive by somehow, the plastic goes into their body and when they are milked the part of plastic come into it and affect us [9]. Apart PS do have certain miscellaneous hazards, PS products are made by petroleum, a non-sustainable and heavily polluting resources. As they are light weight, they float on water which causes water pollution and effect the marine life.

In viewing the hazards of synthetic polymers (such as PS etc., table 1) it is need of the current time that these hazardous entities should be recycle, reuse, reduce, degraded or may be modified in such a way that their menace can be minimized. Recycling of PS and other synthetic polymers had been proved as one of the effective ways to minimise the production of these material. Most of the PS types like EPS (expanded PS), HIPS (high impact PS), OPS (oriented PS), Styrofoam etc. are accepted for recycling purpose [10]. Methods like, mechanical, chemical and thermal recycling of PS is generally employed however not 100% of polymer get recycled due to certain technical reasons. The process like chemical recycling need certain chemical which could be hazardous, while thermal recycling can produce
harmful gases in the atmosphere. However minimization of PS etc. by recycling can’t totally eradicate the negative effect of theirs. Therefore some other alternatives are to be employed to cut down the production as well use of these synthetic polymers. One of such a way is modification of synthetic polymer with the help of biopolymers [11].

2. PS composites for minimizing its hazards:

2.1. Binary Composite:

**PS/Starch:** Starch is a natural polymer having interesting properties. It is biodegradable, low cost and a renewable source. Starch consist of two types of macromolecules, amylose and amylopectin, which are structurally different. Amylose is linear polysaccharide with a molar mass in range of $10^5$-$10^6$ g/mol. Amylopectin is a branched polysaccharide with a large degree of polymerization and molecular mass about $10^8$ g/mol. Increasing the starch content will decrease the melt strength of the material and increase the density. [12]. Berruezo et. al. 2013, [13] prepared composite of thermoplastic starch (TPS) with PS in various ratio (10-50%). These composites were cast to thin films and were subjected to studies like, SEM, TGA, DSC, tensile strength, biodegradability etc. It was observed that the thermal degradation was increased with increasing amount of TPS in the composite, similarly the effect of PS was pronounced over TPS which was found with DSC curves. Biodegradability of the sample was observed, the samples were found to have lower mass after soil exposure for number of days (151, higher for the sample containing higher %age of TPS), which was also supported by DTGA studies. The 50:50 blend sample shows decreased Young’s modulus (by 48%), decreased tensile strength (by 62%) and increased elongation at break (by 62%), as compared to PS. Pushpadass et al. 2010, formed composites of corn starch with PS ( in ratio of 80:20 and 70:30) and studied the effects of temperature and moisture on the physical properties and biodegradability, while FTIR and NMR studies were carried on to notice the change in the structure. In IR there is change in wave number by (2-3 cm$^{-1}$) towards higher wave number which tells about the bond is getting weaker, degradation is going on after 30 days of biodegradability studies. The biodegradability was notice for composite having 70% and 80 % of starch which were found to degrade completely within 39 days in the chamber at 45 °C. They also have noticed the effect of citric acid on the properties composite like it becomes brittle and crunchy and were degraded faster with peak release of CO$_2$ nearby by 15$^{th}$ day [14], this results with fibrous PS which is thought to get degraded faster due to its higher surface area provided to act by microbes.
Oliveira et al. 2010, prepared composite of starch/PS (20/40/60 of PS by wt%) and check their biodegradability by SEM. The samples were buried under the black subsoil (30% bovine manure) in normal conditions. After every 15 days the sample was tested with proper cleaning the weight loss was noticed which give sign of degradation. The problem of phase separation was minimised by addition of maleic anhydride (MA) which increases the interfacial adhesion between the two phases. The weight loss is maximum in the sample containing 60% of starch, suggesting that higher the content of starch higher the degree of degradation of the sample. The biodegradation rate increased to the maximum in first 15 days for the 60% of starch sample. SEM (60% sample) provide the effects of microorganism on the surface generating voids of different shapes due to biodegradation [15].

Gutiérrez et al. 2017, Properties of native and oxidised corn starch was studied by preparing a blend of starch and PS with the help of a catalyst (zinc octanoate) by compress molding. For characterization of the film IR, XRD, SEM, TGA, DSC were used. The results shows that there was cross linking between the PS and starch due to the usage of catalyst it was shown by the molecular method in which the molecular weight of the oxidised blend is having higher molecular mass as compared to the normal blends of starch/PS. From IR studies it was concluded that the starch was oxidised because a peak at ~ 1641 cm\(^{-1}\) which was due to symmetric stretching of carboxy groups. By the studies of DSC it was observed that the \(T_g\) of oxidised corn was lowered as compared to the normal, this is due to lowering of starch bond-strength. From TGA the results were the same getting from the DSC the \(T_g\) and decomposition temperature of oxidised corn was lowered as compared to the normal starch. The XRD studies shows that the normal blend is more crystalline in nature as compared to the oxidised starch blend by which it was confirmed that there is cross linking in between the oxidised starch blends [16].

Yayshahri et al. 2019, PS/corn starch blends were made in presence of glycerine as a plasticiser via melt extrusion method by a twin-screw extruder. The novelty of this work is that the use of pre-gelatinized corn starch that may be a new changed corn starch. The study of the blend is done by SEM, TGA and biodegradability. The SEM results proved that dispersion of starch in PS matrix was smart and because the glycerol/starch quantitative relation was increased, blends with additional entire morphology were made. The TGA curves showed that starch and glycerine within the samples buried within the soil for eight weeks were eliminated by actions of micro-organisms. it absolutely was verified that thermal and impact properties of blends area unit captivated with their morphology in a way that Izod impact strength was reduced by increasing the quantity of starch and glycerine. The same result was perennial for un-notched Izod however in larger values of impacts. Soil burial
check showed that because the quantity of glycerine and starch was increased, degradation rate and weight loss were increased too. Weight loss was rapidly raised within the initial period of time of the check on the other hand it was reduced by time [17].

**PS/Sugarcane Bagasse:** There are interesting composite of plastic with the agroindustry residue. Natural fibers due to here biodegradability and reinforcing properties they are good as a composite material. This composite is giving a stronger approach of adhesive and shows higher thermal stability [18]. Meireles et al. 2007, the study of blend compatibility of waste materials (Cellulose Acetate) with PS with the help of FTIR, DSC, TGA, SEM. Many blends were prepared having different composition of PS% (10,30,50,90). By studying these compositions, it was noticed by FTIR that 30% was a limit for occurring a reversal in-between matrix and dispersed phase. From FTIR this was also observable that there was a miscibility region (where mixture exists for 2 or more phases, they are not completely miscible), which was very clear that the region is of van der Walls forces [19].

Liyana et al. 2008, Blends of PS/Bagasse were prepared of different ratio’s (20/30/40 % of PS). Biodegradable composites blended with fibres once being changed or treated by alkali treatment were ready and conjointly the mechanical properties were investigated. The biocomposites panel samples were processed by hot press machine. The PS was supplemental as a changed from natural fibers to see the impact it had on physical and mechanical properties of the panel. Surface hardness price, compressive strength, bending strength and bending modulus values all will increase in rosin content level and panel density. Water absorption test was done, and it was found that as there is increase in fiber the absorption value increased. As compressive strength was also studied, and it was found that with the increase in fiber ratio, the strength is decreased [20]. Zizumbo et al. 2011, Sugarcane fiber were blend with dichloromethylvinylsilane and grafted with PS. It was observed that the interfacial adhesion was increased in the composite and it was observed by TGA. The silanized and styrene grafted fibers showed a higher thermal stability than those non treated fibers. The mechanical properties like Young modulus were improved with just a rather loss of enduringness. SEM microcopies and size distribution analysis for the fibers showed that improvement of the mechanical properties for composites were better surface adhesion between fibers and chemical compound matrix. Results show that PS-grafted sugarcane pulp fibers are helpful reinforcing additives to extend mechanical behaviour of recycled PS composites [21].
PS/Carbon nanotubes: Carbon nanotubes can significantly reinforce composites because of its mechanical properties. Carbon nanotubes have high electric and thermal conductivity which make the more functional composites [22]. Kaseem et al 2016, PS/CNT composite was made by melt mixing and in-situ polymerization. The main discussion was on covalent and non-covalent changing of CNTs with PS which had a major positive impact on the dispersion and compatibility of the PS/CNT composites. The process of melt mixing had a huge role in large scale production. CNT act as nucleating agent which is increasing the crystallization rate of PS. It also increased the thermal stability of PS, and about the mechanical properties, Young’s Modulus and tensile strength is increased as we increase the amount of CNT in the composites mean while the electric conductivity was also increased with the addition of CNT in composite [23]. Yuan et al. 2009, Multi walled CNT were changed via chemical process of cinnamene underneath microwave irradiation and melt mixing process. It increased the compatibility of PS and poor polar materials by applying a layer of CNT over PS. For further studies TEM was used which provide the information that the dispersion ability of CNT was improved a lot. Tensile strength was also increased a bit. When the CNT is used in between the layers of PS matrix strong interfacial adhesion was observed which was important for an excellent polymer nanotube composite [24].

PS/Agave fiber: Natural fibers are excellent reinforcing materials for composites. It is cheap, biodegradable in the nature, easily available. It provides tensile and flexural strength, higher thermal stability. Mechanical properties are found much better when reinforce with fiber [25]. Moscoso et al. 2012, composites were made by blending PS/Agave fiber by compress moulding and result shows in the tensile strength and Young’s modulus increased with the increase in the content of fiber. From further studies of TGA it was observed that after the blending composite become more thermal stable and also thermal depolymerization was observed at lower temperature where it was a slightly damage to the glycoside’s groups of cellulose. From DSC the Tg of the composite was slightly increased with the fiber content. It was also observed that the crystallinity was also increased when fiber is added to it [26]. Cindu et al. 2018, Different composites of PP, LLDPE, HDPE were blended with agave fiber and further studies of mechanical, chemical, thermal properties was done. By FTIR the chemical properties was studies which doesn’t have a significant change which shows that there was not much chemical interaction between natural and synthetic material chemically, so it was clear that there is no chemical bonding but just physical interaction between the material. There was a slight increase in thermal stability of the
Composite when it was reinforced with the natural fiber. The tensile strength and Young’s modulus was increased as natural fiber content is increased. The ratio of fiber in the composite is from 0-30%. When the fiber content is 20% by weight then the elastic modulus was observed highest. For LLDPE, at 20% of fiber content the yield strength was maximum but in case of HDPE and PP when the content was at 30% the yield strength was observed maximum [27].

**PS/Wood flour:** Wood industry produce huge amount of waste of wood which is disposed in landfills or burned. The addition of wood flour to the waste polystyrene is a good combination resulting in a composite having viable mechanical properties and environment point of view. With the coupling agent mechanical properties increases but without them it decreases. Composite density increases with increase wood flour content [28]. Lisperguer et al. 2010, composite was made of PS with different composition (30% & 50%) of wood flour by melt method. Further studies were done by the DSC and TGA. The best result for impact strength was for 30% of wood flour composite, mechanical properties were increased and can be seen by the good dispersal of wood in the composite. From TGA studies it was observed that the T_g was shifter towards higher side as compared to the pure one which also shows that it’s thermal stability also increased, and it was also observed that the wood flour also increased the stiffness of the composite [29]. Poletto et al. 2011, made composite from PS/Wood flour (10% to 40%) and adding coupling agent (poly-styrene-co-maleic anhydride) of 1% to 4 % by weight. Small fiber are used to increase effective surface area so that the mechanical properties increases, as well as for the wetting with polymer matrix. The addition of wood flour the PS increases the stiffness of material but decreases the flexural strength decreases up to 20% after that there is decrease in strength which was explained on the behaviour of hydrogen bonding which decreases the mechanical properties. Effect of coupling agent was to give a increases in adhesive force between the fiber and matrix, due to this increase there is increase in the flexural and impact strength this was also up to 2% after there is also decrease in mechanical properties [30].

**PS/Lignin:** Lignin is a natural polymer present with cellulose and hemi-cellulose, major component found in woody structure of plants. Polystyrene thermal stability can be improved with the addition of lignin. They are produced by melt mixing. Compatibility is good due to similar aromatic structure [31]. Zhang et al. 2018, PS and lignin composites are made and studied for different properties, from FTIR it was observed that after the blending was done there is an ester peak in the spectrum which was not found earlier, further peaks for
The hydroxy group was not found in the composites which was there earlier. The $T_g$ of the composite was observed and found out to be slightly lower that the original material as the lignin content increases which is due to hydrogen bonding and molecular restriction. It is observed that there are synergistic effects on the composite toughness [32]. Reza et al. 2012, blends were made of PS and Lignin with different composition (0% to 80% by weight). Observation are made like the $T_g$ was observed at a higher temperature there will be crosslinking possible. This shows that the lignin is acting as a filler in the composite. From SEM it was seen that there is rough surface which show that there is poor wetting and poor interaction between the particles of lignin and PS which leads to poor mechanical properties. Flexural and shear moduli increase as we increase the amount of lignin. When the tensile strength has been observed it was uniformly decreasing with increasing in amount of lignin which can happen due to irregular surface of lignin particles, and another can be the poor interaction between the lignin and PS [33].

2.2. Ternary Composites

PS/AA/ montmorillonite: Montmorillonite is commonly found in bentonite which is a sheet like clay which is widely used for its low cost and naturally abundance. This composite is widely used as a superabsorbent hydrogel. The addition of bentonite can improve the thermal stability of material [34]. Alshabanat et al. 2013, Polymer nanocomposites of polystyrene framework containing 10% weight of organo-montmorillonite were readied utilizing the arrangement strategy with sonication time (0.5, 1, 1.5, and 2 hours). CTAB is utilized to alter the montmorillonite soaking its surface with Na+ particles. For further studies FTIR, SEM, TEM, XRD and TGA were used. From FTIR it was observed that the peaks were shifted when they were blended with montmorillonite because it was inserted in between the layers of polymer by secondary valence forces. XRD was providing the information about the interlayer spacing in clay layer. The timing after 1 hour of sonication is giving intense peak which indicates that after one hour the MMT is started inserted in the PS. From SEM images it was easy to study about the surface of material, it tends to be resolved that intercalated structures and a very limited quantity of shed structures were shaped, which confirms and concurs with the XRD result. From TEM it was observed that there is crystallinity behaviour of our material, after the sonication of material to 1 hour, crystallinity was found to be increased. From TGA it was observed that there is increase in the degradation temperature, this was observed due to restriction to the motion of particles and due to increase in crystallinity of polymer [35]. Chengcheng et al. 2019, in this work, effect
of double functionalized MMT on structural, thermal, morphological changes were observed. From FTIR, it was observed that asymmetric and symmetric vibration of -CH$_2$ of phosphonium surfactants which tells us that there is successful fitting of molecules in the interlayer space of MMT. There was significant decrease in some peaks which clearly states that there the material had changed its behaviour form a hydrophilic to a hydrophobic character and water content also decreases in the material. From XRD, the observations are that there in increase in the interlayer space of MMT which supports the FTIR results. From TGA and DTG it was observed that the mass loss of material was more as compared to the virgin material which clearly states that there is insertion of MMT in the material. As MMT is introduced to PS, particle size of PS decreases, increased friction reduce properties [36].

**PS/PE/SEBS:** Polystyrene (PS) and low-density polyethylene (LDPE) are most used polymer in the world. As LDPE has low modulus but great toughness on the other hand PS has high modulus but brittle in nature. Therefore, mixing both is a great idea but due to their nature they for a heterogenous mixture to overcome this disadvantage a compatibilizer is used which is polystyrene-block-poly(ethylene-ran-butylene)-block-polystyrene (SEBS) which make PS and LDPE to interact with each other and form a good composite having good mechanical and thermal properties [37]. Parameswaranpillai et al. 2018, a ternary composite was made from PS/LDPE/SEBS of different composition but the best composition that give good result of mechanical and other properties is 33/33/33 by weight. It was observed that stress was minimum in the ternary composites is minimum as compared to the binary composites. From SEM it was observed that the surface was uniformly distributed in the 33/33/33 composition, PS matrix is more elongated and formed an interpenetrated continuous morphology. The strength of the composition (33/33/33) was increased tremendously, the result shows very good strength, toughness, ductility and this was due to strong interaction of PS/LDPE with the SEBS. It was a great chance in terms of mechanical properties of composite that addition of SEBS will increase that much of strength that other can’t that was due to the surface modification done by SEBS so that there is much better interaction happens in between the PS/LDPE and SEBS which it can be useful in high performance applications [38]. Parameswaranpillai et al. 2015, composite were made of PP/PS/SEBS by melt mixing method and its different properties like thermal, mechanical, viscoelastic, crystallization were studied. The use of graphene was also studied and as the content of graphene was increased the tensile strength decreases in PP this may be observed due to formation of voids in the matrix. But as soon as addition of graphene in PP/SEBS there
was increase in tensile strength. There was a drastic change observed in the presence of SEBS. Which suggest that SEBS is a very good dispersive reagent which improved the dispersion and acts as a good interface between matrix and filler. From TGA the thermal stability was studied which states that the composite PS/PP/SEBS was very stable thermally. From DSC it was clear that the increases in content of graphene into the composite, it increases crystalline nature of the material [39].

**PS/PPS/Carbon nanotube:** The composite is made by controlled melt blending process to produce a conductive polymer. CNTs have greater potential for decreasing the electrical resistivity of a polymer blend. Processing of these composite below the temperature will not affect the CNT conductive network [40]. *Yang et al. 2005,* The composite is successfully fabricated and tested for many properties and found that this composite of PS/CNT/PPS can be used in lightweight shielding material. In the composite if the conductive filler attain the major concentration then the material as whole become conductive by forming a conductive network. For shielding effect the dependency is on the filler as the concentration of filler increases the shielding effect increases but the mechanical properties decreases. The shielding effectiveness is due to the network structure of carbon. Carbon nanotube allows at low concentration of filler the desired electrical and shielding properties [41]. *Shrivastava et al. 2011,* polymerization is done of styrene and CNT/PS conduction composite with very less strain. The conductivity was attained through the homogenous dispersion of CNT. It was observed that there is increase in electric conductivity with the increase of PS composition at a constant concentration of CNT which was justified based on continuous network structure of CNT in PS matrix. The material having 70% of PS had showed the maximum conductivity. Presence of PS blends increase the concentration of CNT in the PS phase of composites. Thus the CNT cannot pass through it and increase the CNT concentration which increases the conductivity of material [42].

2.3. Miscellaneous (Multicomponent) Composites:

Polypyrrole (PPy) is a good adsorbent of heavy metal ions from the water which is one of the serious problems of today’s world. The composite of PS and PPy can take out Cr (IV) ions from the water. Kinetics of the reactions tells that it is pseudo second order reaction. From SEM it was studied that the composite have a uniform morphology, microsphere with largely shrink surface. The sharp contrast from the side and light from the centre suggest that it is hollow inside. Adsorption of Cr (IV) from the water is observed as before addition of
composite the sample was yellow in colour but as soon as the composite was added the colour disappears and some of the Cr (IV) is converted into Cr (III) by the PPy [43]. A sandwich type composite was prepared from the PS/PPy/ SiO$_2$ in which the SiO$_2$ is moveable so that the composite can be made hollow at any time also. The diameter of the multilayer sandwich type composite can be controlled by adjusting the concentration of PPy. Due to the movable SiO$_2$ the conductivity of the composite increases. PPy is the major factor on which the conductivity increased with the increases int concentration of PPy. Due to this there is huge application the field of conducting building block. Different concentration of PPy (35 – 50 % by wt) were made to form different composites and conductivity was increased from 1.20 to 4.90 S/cm [44]. The different composites were made with PS and natural fiber of different husk like rice, wheat, mustard husk. The different size with different composition were studied for their mechanical behaviour like tensile and flexural strength. For the tensile strength rice and mustard husk will increase strength up to an extent then decreases but not in case of wheat, in wheat the tensile strength increases with increase in the filler composition in the composite due to the better dispersion of the particles. For flexural strength, the smaller size fillers very giving good results, the flexural strength increases with increase in concentration of filler. The micrographs tells that the composites made by rice husk were the best in terms of filler particles [45].

3. Factor affecting composite nature:

**Synthetic Polymer:** Synthetic polymers are those which are synthesised in laboratory or simply human-made polymers. Synthetic polymers can also be used as clinical medicine [46] Polymers are those which consists of repeated structural units known as monomers. A monomer is a small molecular subunit that can be combined with similar subunits to form larger molecules. Simplest example of synthetic polymer is our polythene. Polythene is used in our daily life and it is made up of monomer unit ethylene and when it is converted into polymer and known as polyethylene. Polyethylene is of the simplest polymers, created by radical mechanism.

**Polymer blending:** Blending is a gentle process over mixing in this very gently combination of materials is done whereas in mixing vigorous combination take place, blending leads to separation, aeration [47]. Blending now a days is becoming very popular because blends of
natural and synthetic polymers results into new material which is more useful and less dangerous to our environment [48].

**Biocomposites/biomaterial:** That material formed by a matrix and reinforcement of natural fibers. Biocomposites are combination of natural fibers like wood fibers (hard wood and soft wood) or non-wood fibers (wheat, hemp, jute) with the polymer matrix synthetic polymer or semisynthetic polymer [49].

**Temperature:** The material of PS was studied under different temperature and it was observed that when temperature is increased from 120 °C to 130 °C the tensile strength was increased due to the vaporization of water present in the matrix as the water contact decreases the interaction and space between the particles decrease which lead to increase in the tensile strength but when temperature is increased too much around 170 °C the tensile strength again started to get decreasing due to breaking of bonds [50]. Sheinker et al. 1956, The other major factor that can be studied or controlled by the temperature factor was the configuration factor i.e. cis or trans polymer it is reliant on the temperature factor. The strength of polymer also depends upon this whether it is trans or cis. At a certain temperature if polymerization was done then there will be formation of both, but when the temperature is increased the concentration of trans is decreased by some extent [75, 76].

**Catalyst:** It was seen that with increases in temperature of the reaction, product yield increases but if we use catalyst (AIT100s) it produce the same amount of product at lower temperature. It was observed that the yield is about 99% in case of catalyst but less in case of temperature increasing procedure. It was observed that using catalyst in these types of reaction like polymerization type of it increase the yield of desired product and decrease the harmful effects of the waste polymer compounds [51]. Catalyst not only increases the amount of product but also decreases the time of reaction. Tripathy et al. 2005, describes the same about the catalyst effect on polymerization. There are different type of catalyst for different type of works like for lessening of time there is stannoxane catalyst which ends the reaction in 2-3 min at 190°C, butyltin chloride dihydroxide completes the reaction in 3-5 min at 190°C. As they decreases the time of reaction but increases the crystallinity of the polymer which result into the loss of ductility. Tetrakis-(2-ethylhexyl) titanate TyzorOGT was observed as the catalyst that increases the molecular mass at the same polymerization temperature, all other require higher temperature for that higher molecular mass polymer. It was observed normally that with increase in the temperature the crystallinity increases but
with these catalysts it was reversed, at inferior temperature there is unusual crystallinity but at higher temperature there is usual crystallinity [77].

**Crosslinkers:** The work of crosslinkers is to make a network in between the matrix and filler so the tensile strength increases. It was found that the gel content was found more in crosslinker composites, it was amazing to see with the increases of filler the tensile strength of also increase and this is due to the crosslinker it create a network, web like structure which make it harder. Due to crosslinker the adhesive force between two phases increases [52].

**Solvent:** Effect of solvent can be seen of structure, morphology and thermal stability. With toluene it was observed from XRD, that there is no specific peak which tells us the lost of clay layer, also it shows the highest basal spacing between the PS and filler. When chloroform or CCl₄ is used it was observed from SEM the dispersion of filler is good but the basal spacing is low as compared to toluene, whereas other solvent causes a phases separation. From DSC, Tₜ was observed and there is increases in the value of Tₜ when the solvent is toluene, it makes the filler to disperse on the surface uniformly so that interaction is good which increases it thermal stability [53].

### 4. Polystyrene based composites and environmental sustainability:

PS based composites are found to be associated with variety of advantages which not only include the mechanical and physical factors but also it strides a significant step towards the environmental sustainability. Studies shows that PS based composites provides significant reinforcement to the fabricated composites the thermal and mechanical characteristics are found to be enhanced with taking PS as a matrix. The composites prepared for PS are found to be light weighted and saves consumption of fuels, increase performance and minimises the emissions of hazardous gases. Apart the composites fabricated are easy to recycle via various conventional methods including mechanical, chemical, and thermal methods [4, 7]. The biodegradation studied by various researcher shows that the presence of biomaterial in the PS composites are easily biodegrade while the shelf life of the materials is between 6 months to year making the composite environmentally benign and commercially viable [10, 11, 13, 14].

**Conclusion:** PS being a synthetic polymer is used very widely in today’s world due to its high strength and cheap manufacturing but owing to its non-biodegradability it survives in different components of ecosystem thus causing environmental hazards leading towards perilous effects to human body especially causing cancer. To cope with this till date, researchers had fabricated numerous composites which depending upon different fabricating
factors viz., solvent, method, catalyst, curing temperature and cross-linkers which can mitigate the problem of non-biodegradability of PS, as well these composites can be used for manufacturing basic commodities owing to their increases strength and flexibility. Looking into these properties of PS based composites, it can be said that the composites can be proved environment benign and less hazardous. However more modified and advanced research is required for reducing the use and hazards of synthetic polymers.

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| S. No | Polymer | Density (g/cm³) | Tg (°C) | Production (million metric ton) | Applications | Hazards | Ref. |
|-------|---------|----------------|--------|---------------------------------|--------------|---------|------|
| 1     | HDPE    | 0.941          | -110   | 52                              | Detergent bottle, milk jug, bottle caps, drinking straws, car bumpers | Emits dioxins, irritating gas, effect human endocrine glands, effect aquatic life, | [54, 55, 56] |
|       | LDPE    | 0.910-0.940    | -110   | 64                              |              |         |      |
| 2     | PS      | 0.96-1.04      | 56.8-109.7 | 25                          | Refrigerator liners, food packaging, vending cups | Toxic, Carcinogens, Hormonal disruption, Chronic disorder, can causes fatigue and damage liver and nerve tissue, Lymphomas and Leukemias(form of blood cancer) | [57, 58, 59] |
| 3     | PVC     | 1.38           | 71-80.2 | 38                              | Squeeze toys, diaper covers, matters covers, rain coats, hats, shoes, pet toys, building materials, food packing | Highly carcinogen, Toxic, Neurotoxin, Kidney disease, Air toxic, Asthma | [60, 61, 62] |
| 4     | PP      | 0.855          | 100    | 68                              | Packaging foam, Food containers, Plastic tableware, | Allergic reactions, Harmful for endocrine system, genetic mutations, Tumor, Causes problem | [63, 64] |

Note: Tg stands for glass transition temperature.
| No. | Material | Density | Thickness | Tm | Toxic Effects |
|-----|----------|---------|-----------|----|---------------|
| 5   | PMMA     | 1.18    | 0.048-0.8 | -20| Neurotoxic, Cardiovascular, Poisonous |
| 6   | PU       | 0.048-0.8 | 0.048-0.8 | -20| Respiratory toxin, diisocyanates |
| 7   | PET      | 1.38    | 67-81     | 33 | Toxic, vomiting, diarrhea and stomach ulcers |