CHAPTER 1

INTRODUCTION

1.1 POLYMERS AND POLYMER BLENDS

About half of the total polymers produced and used in the world is composed of polyolefins. These are the cheapest plastics and are largely used for short-term packaging. Because of the low density and hollow shape of the items, they emerge both in waters and landfills, provoking considerable environmental impact [1, 2].

The simple processing of mixed polyolefin waste usually leads to products with low mechanical properties because these polymer mixtures are frequently incompatible and contaminated by impurities [3]. Polypropylene due to its favourable price, density and versatility is gradually replacing many materials in commercial applications. Even though this polymer is highly susceptible to photo-degradation, it is commonly used in producing many materials that are exposed to atmosphere like packaging materials and automobile bumpers. The radiations absorbed by the polymer causes removal of hydrogen atoms attached to tertiary carbon atoms leading to the reduction of molecular weight with modification of the chemical structure [4].

The incompatibility of PP with both LDPE and HDPE causes loss of the mechanical properties of the blend. Recycled LDPE and HDPE are difficult to completely separate from the other polyolefins because of their
close densities and similarity of physical properties. So the recycled product may contain fragments of PP as contaminant [5, 6].

The main goal of combining two or more polymers is to obtain a material with appropriate features and conditions for processing. Post-use polymers are mixed in order to recycle such materials and to reduce the environmental impact generated by these solid materials. It is important to determine the behaviour of these materials in order to optimize the non-used polymer/recycled polymer relation and to obtain suitable properties that do not result in a deterioration of the finished product [7].

In recent decades the total consumption of plastics and their applications have increased manifold due to the properties of these materials, their adaptability and use of economic manufacturing methods. Due to large scale usage, a great amount of plastic waste is generated which is causing environmental problems [8].

Due to the immiscible nature of the components, both in the melt as well as solid state, resulting blends show deterioration in impact performance and tensile properties [9].

In many industrial applications of polymeric materials, several criteria play important roles in the selection of resins. In terms of overall performance, these generally include (1) The bulk properties, (2) The surface properties and (3) The processability of the resin. Bulk properties are critical in determining the thermal behaviour and mechanical strength of polymers [10,11]. On the other hand surface properties play important roles in determining the wettability and adhesion, friction and wear, gloss
and scratch resistance, paintability and printability, biocompatibility and antistatic properties [12]

The majority of polymers found in waste plastic streams form phase separated morphology. Properties like ductility and impact strength should be improved by compatibilization.Compatibilization is done by the addition of block or graft copolymers with segments capable of interacting with blend constituents. These copolymers lower the interfacial tension and improve adhesion between the matrix and dispersed phase [13, 14]. According to Xanthos (1992) chemical modification of a blend by reactive extrusion can improve the properties of the polymer blend [15]

Hettema et al. claim that reduction of rheological mismatch for a blend containing low viscosity PE and high viscosity PP can enhance dispersive mixing. This is caused by preferred reaction of these polymers with peroxides. They have also claimed that the low molecular weight compounds used in reactive extrusion are usually added in relatively low concentrations. They offer considerable economic advantages versus polymeric compatibilizers that are more expensive and usually only effective at higher concentrations [16].

Randall et al. describe the preparation of impact modified PP blends by treating a reactor blend of PP and LLDPE with peroxide. Various fragments will be present and they recombine to form block or graft copolymers. This method increased the Gardner impact strength [17].
Gongde Liu et al. also showed that addition of PP to UHMWPE improved the processability of the blend compared to UHMWPE or its blend with HDPE [18].

According to Deanin and Chung the poor impact resistance at low temperature and poor environmental stress cracking resistance has set limitations to the use of polypropylene. These properties of polypropylene can be improved by incorporation of ethylene during polymerization or mechanical blending with polyethylene. Propylene – ethylene copolymers give better performance than PP at low temperature but these copolymers require controlled, specialized polymerization during manufacture and so are more expensive. Thus blending of PP and PE is an economic alternative [19].

According to Nolly et al. and Bartlett et al. samples prepared by compression moulding were less ductile and less strong than those prepared by injection moulding [20, 21].

An increase in the mixing time as well as intensity improved the degree of dispersion but prolonged or intensive mixing also increased the thermal and mechanical degradation. There is an optimum mixing procedure that should be sought [22].

Polyolefin are the most important plastics. Polyethylene and polypropylene have the most products and lies in the first position of plastics. Polyolefin blends are frequently used to get the balanced mechanical and processing properties. The properties of individual polyolefin can be changed in a significant way by mixing with other components. For this reason polyolefin blends have attained widespread commercial applications. Many studies have been conducted to study the
relationship between morphology and properties of polyolefin blends and to control the micro-phase separation, morphology and orientation of studied blends in order to get excellent properties [23 – 25].

Study of properties and morphology of polyolefin blends is of great interest importantly because of their rich and fascinated morphology depending on molecular structure; thermal history and external stress field. The work of Prof. Bevis, oscillating shear stress field has been very important in controlling polymer morphology and mechanical properties.

It was found that HDPE and PP were phase separated in the melt state and form separated crystallites during cooling. However a study of PP/HDPE blends by Inoue and coworkers proposed a single phase mixture of PP/HDPE = 60/40 obtained in high shear fields in an injection moulding machine based on the regularly phase-separated structure [26].

Macosko et al. observed the average diameter of particles of the blend with and without compatibilizer. They noted that less than 10 minutes of mixing even at very low shear rate was enough to reach the final particle size. Most of the size reduction occurred very rapidly during the softening of the pellets or powder. The particle size was slightly smaller with the block copolymer present [27].

It is interesting to check the miscibility, morphology and mechanical properties of polymer blends in a high shear rate combined with oscillating shear field during cooling. Experiments were carried out for HDPE/PP blends via oscillating packing injection moulding after subjecting a high shear rate at the nozzle. A great enhancement of tensile strength was achieved for the blends with PP content less than 10 weight percentage [28].
1.2 POLYMER BLENDING

The practice of polymer blending is as old as the polymer industry itself. During the first half of the twentieth century, the greatest progress in polymer industry was the development of a wide range of new polymers. This was based on the new understanding of polymer synthesis and the development of commercialization of economical manufacturing methods for a range of monomers. Most of the major commodity and engineering plastics in current use were being manufactured in 1950's. By 1970 most of the common monomers had been exploited and then only a few new developments have been taken place in synthesis, generally reserved for specialized polymers and to low volume applications.

During the same period polymer blending began to flourish. It was gradually accepted that new economical monomers were less likely but a range of new materials could be developed by combining different existing polymers. While most monomers available cannot be copolymerized to a product of intermediate properties, their polymers could be melt blended economically. Now polymer blends in one form or another dominate much of polymer practice. This rapid development can be attributed to the following points –

1. The opportunity to develop new properties or improve on properties to meet specific customer needs.

2. The capacity to reduce material costs with little sacrifice in properties.
3. The ability to improve the processability of materials which are otherwise limited in their ability to be transformed into finished products.

4. Permit the much more rapid development of modified polymeric materials to meet emerging needs by by-passing the polymerization steps.

1.3 IMPORTANT BLENDING PRINCIPLES

Polymer blends may be broadly classified into two – miscible and immiscible blends. Miscible blends are characterized by the presence of a single phase and a single glass transition temperature. They involve thermodynamic solubility. Their properties can be predicted as composition weighed average of the properties of individual components. Immiscible blends are phase separated, exhibiting the glass transition temperature and/or melting temperature of both components. The overall performance of the blend depends on the properties of the individual components as well as the morphology of the blends and the interfacial properties between the blend phases. For a polymer blend to be miscible, the free energy of mixing should be negative which means that the blend should have an exothermic heat of mixing. An exothermic heat of mixing can be achieved by the introduction of specific interactions between blend components. These interactions range from strong covalent and ionic bonding to weak non-bonding interactions like ion – dipole, dipole – dipole, donor – acceptor interactions etc.

During blending of two polymers we have to take care of a few possibilities. Simply adding a polymer to another brings out both good
and bad properties of the later. The adverse effects are so pronounced that the resultant material is most likely unusable. The main reason is that most polymer pairs are immiscible and blending leads to a phase separated material. This material has three inherent problems.

a) Poor dispersion of one polymer phase in the other

For most polymer pairs, the interfacial tension is high of the order of $1.5 \times 10^{-3}$ to $1.5 \times 10^{-2}$ J m$^{-2}$. This high value makes dispersion of one phase in the other by melt blending difficult. When the dispersed phase has large surface area, the interfacial contact between the two phases is small. When this material is subjected to mechanical load, it does not respond efficiently.

b) Weak interfacial adhesion between the two phases

For most polymer pairs, the Flory parameter $\chi$ is large (0.05 – 0.5) and the interfacial width ‘h’ is narrow (1 – 5 nm). This means that there is little penetration of polymer chains from one phase into the other and vice versa, and consequently few entanglements are formed across the interfaces [29]. The failure of the interface between two glassy polymers thus requires only the breaking of weak van der Waal’s bonds. For most incompatibilized blends, the interfaces are probably the most vulnerable locations. When they are subjected to an external stress, the interfaces will most likely fail well before the base polymer components.
c) Instability of immiscible polymer blends

An immiscible polymer blend is thermodynamically unstable. The state of dispersion of one phase in another is governed by both thermodynamics (interfacial tension) and thermo-mechanics (agitation). It is a result of the competition between the interfacial energy of the system which encourages maximum separation of components, and the external mechanical agitation imposed on it, which is to induce mixing. Agitation produces flow stresses which tend to deform and break domains. Interfacial tension opposes the deformation and break-up of domains and encourages coalescence of the dispersed phase domains when they come in close proximity. When agitation ceases the interfacial tension becomes the driving force for the system to evolve. Each phase will coalesce; minimize the total interfacial area as well as the total interfacial energy of the system. Coalescence is slow in an immiscible polymer blend but is still too fast for most practical applications. Due to the instability of the blends, the morphology of the blend depends on the conditions to which it is subjected. The morphology of an immiscible polymer blend obtained from a screw extruder may not be the same as that when the blend is injection moulded.

Immiscible polymer blends are much more interesting for commercial development since immiscibility allows to preserve the good features of each of the base polymer components of the blend. Some properties can be achieved only through immiscible polymer blends. For example the impact strength of a polymer cannot be improved significantly by adding an elastomer miscible with it. Our challenge is to develop processes or techniques that allow control of both the
morphology and the interfaces of a phase separated blend. Such processes or techniques are called compatibilization. Polymer blends with intentionally modified morphology and interfaces are called compatibilized blends.

Compatibilization techniques have been inspired by colloidal science. Addition of a graft or block copolymer to an immiscible polymer blend plays the role of an emulsifier or surfactant in a water–oil emulsion. The compatibilizer has an additional role of enhancing interfacial adhesion between the two phases. Such a compatibilizer is also known as interfacial agent, emulsifier or adhesion promoter.

There are three distinct strategies for compatibilizing immiscible polymer blends.

1. Non–reactive compatibilization – by adding non–reactive block or graft copolymers.
2. Specific compatibilization – groups having specific non–bonding specific interactions are attached to polymer chains.
3. Reactive compatibilization – introducing reactive molecules capable of forming the desired co-polymer in situ, directly during blending.

The classical approach to compatibilizing immiscible polymer blends is the non–reactive compatibilization. A well selected copolymer having two distinct segments when introduced into an immiscible polymer blend will be located at the interphases. Each segment will penetrate to the phase with which it has specific affinity. This will reduce the interfacial tension, enhance interfacial adhesion, promote dispersion
of the dispersed phase in the matrix and stabilize the morphology of the blend [30 - 34].

But this approach bears two major limitations.

1. Each immiscible polymer blend needs a specific block or graft copolymer as compatibilizer. A particular synthetic procedure is required to prepare each of them which are often tedious and costly. For a large number of immiscible polymer blends, synthetic procedures are unavailable for the preparation of block or graft copolymer.

2. The amount of block or graft copolymer to be added to a polymer blend is much higher than the required to saturate the interfaces. Due to thermodynamic and thermo mechanical reasons some of the compatibilizer added may not reach the interfaces. For the copolymers to reach the interfaces, it has to undergo melting / plasticization, dispersion, solubilisation and molecular diffusion. The copolymer has to be dispersed first in sufficiently small domains so as to be solubilised by chain entanglement and distributed as single macromolecular chains and / or micelles in the base polymer components. These solubilised macromolecular chains reach the interfaces by molecular diffusion. But the time required for this process is much higher compared to the residence time of a blend in the extruder / mixer. Therefore major problems facing non-reactive compatibilization are how to reach the compatibilizer to the interface [35].

The effectiveness of block and graft copolymers as compatibilizers have led to a revolution to devise new approaches to produce new block and graft copolymers for the purpose. The most important is the in-situ preparation of compatibilizer during melt blending by the use of reactive
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polymers. During reactive compatibilization of immiscible polymer blends three main scenarios are observed.

1. The base polymer components are mutually reactive. The reaction between components leads to the formation of a copolymer and compatibilization is straightforward. Most polycondensates are of this type with functional groups at the ends.

2. One polymer (A) bears potentially reactive groups and the other (B) is chemically inert. The non-reactive polymer is functionalized with a functional group that can react with reactive groups that can react with reactive groups on (A). This leads to a reactive copolymer (C) which reacts with the polymer (A). The compatibilizer will be of A-C type, segment A miscible with polymer A and segment C in polymer B.

3. Neither component contains reactive groups. In such cases different compatibilization methods are employed. We may add two reactive polymers C and D which are mutually reactive and are miscible with A and B respectively. The resulting copolymer will be of the type C-D. Or else we can functionalize the polymers A and B with different functional groups which react to form the copolymer [36].

The basic principle involved in non-reactive as well as reactive compatibilization is the same except that in reactive compatibilization, chemical reactions are involved in the blending process. This makes reactive compatibilization very attractive and cost effective.

1. Compatibilizers are generated directly at the interfaces during melt blending without separate synthetic and purification steps.
2. The problem of getting the compatibilizer to the interface is avoided as the compatibilizer is formed at the interface during melt blending. Thus reactive compatibilization is also called in-situ compatibilization or reactive blending.

3. When the desired compatibilizer cannot be synthesized directly, reactive compatibilization is the best method available.

4. The product cannot be de-engineered easily by analysis which provides an element of secrecy to the manufacturer. It is very difficult to extract and characterize the compatibilizer formed. The process can be conducted in different ways with different property outcomes for the product.

The study of reactive polymer blending involves many aspects. Polymer Chemistry and Organic Reaction Chemistry are important in the study of thermodynamics and kinetics of reactions at the interface. The flow regimes in the processing devices need to be studied. The melting and mixing processes control the formation of interfaces as well as control the resulting morphology.

Reactive polymer blending has become a very important contributor in development of new polymer materials. A wide range of commercial processing equipment is used for reactive blending. They are twin screw extruders, Farrel continuous mixers, Buss kneaders and single screw extruders. The machines should be configured to give adequate residence time so that both requisite mixing and reaction can occur. Each blend system has a unique set of processing requirements and we cannot make generalizations on equipment preferences. At present screw extruders play a dominant role in the preparation of reactively compatibilized blends.
1.4 METHODS FOR BLEND COMPATIBILIZATION

1. Addition of Block and Graft Copolymers

A compatibilization strategy used in polymer blending is the addition of a pre made block copolymer composed of blocks that are each miscible with one of the homopolymers [37]. These segments need not be identical with the blend components. According to Noolandi and Hong as well as Leibler, the block copolymers prefer to span the interface [38, 39]. The copolymer locates at the interface between immiscible polymer blend components, reducing the interfacial tension between blend components, reducing the resistance to minor phase breakup during melt mixing which reduces the size of the dispersed phase and stabilizing the dispersion against coalescence. This finer morphology and the increased interfacial adhesion result in improved physical properties.

2. Utilization of Non-Bonding Specific Interactions

Non-Bonding specific interactions like Hydrogen bonding, ion-dipole, dipole-dipole, donor-acceptor and π-electron interactions can be employed for the compatibilization of polymer blends. A large number of such interactions are available in the literature. These specific interactions are weak and high concentrations (one interacting group per repeating unit) are often required for compatibilization. Polymers capable of such interactions cannot be added only in small quantities for compatibilization of blends. The addition of large quantities of the compatibilizer may change the properties of the desired phase constituents and/or be uneconomical.
3. Reactive Compatibilization

Here the compatibilizers are formed in-situ through ionic or covalent bonding during the melt blending of suitably functionalized polymers [40 - 44].

In this type of reactive compatibilization one phase contains reactive groups inherent in the polymer, while the other has no inherent functionality. Reactive groups can be incorporated into the second phase by adding to it a functionalized polymer miscible. In some cases both phases will have to be functionalized. The in-situ formed copolymer compatibilizers get located at the interphase, reducing the size of the dispersed phase, improving interfacial adhesion between blend phases and the physical properties of the blends. This method has been implemented in a number of commercial products and appears to be the method of choice for compatibilization.

According to Utracki all commercial blends made from highly immiscible polymers are compatibilized reactively. A block or graft copolymer is formed by coupling of reactive groups on each of the immiscible polymers [45].

Ghijsels and Raadsen comment that there are several problems in compatibilizing multiphase structures with block copolymer in the melt. The viscosity of the block copolymers is high and thus may be difficult to disperse. Moreover these copolymers are very expensive and we have to minimize their concentration [46]. Hobbs et al. suggest that the block copolymer added to compatibilize the blend should prefer to lie at the interface rather than form micelles or a separate phase [47].
4. Addition of Low Molecular Weight Coupling Agents

Addition of low molecular weight coupling agents may serve the purpose of compatibilization of polymer blends through copolymer formation. A large number of reagents like bis (2-oxazolines), Peroxides and co-agents, multifunctional epoxy monomers, organo silanes, Aluminium Chloride, bismaleimide, methylene diphenylene di isocyanate etc. have been employed for this purpose.

Compatibilization of a polymer blend can be achieved by the use of low molecular weight reagents or a mixture of low molecular weight co-agents to obtain interfacial reaction between polymer components. During the process some type of graft or block copolymer is formed which plays the role of compatibilizer. When we consider a blend of two polyolefins, we have to add two different functionalized copolymers which may not produce required results. In such cases the ability of a reagent to compatibilise the polymer blend in a single reactive step would be an advantage. A free radical initiator like peroxide can promote reactions on a polyolefin chain leading to compatibilization.

1.5 COMPATIBILIZATION OF POLYOLEFIN BLENDS BY PEROXIDES

Peroxides used in a process of in-situ compatibilization of polyolefin blends triggers polymer modifications due to high sensitivity (reactivity) of polyolefins to free radicals. Consider a blend of polyethylene and polypropylene – two common commodity plastics. These two polymers are immiscible due to difference in their molecular structure. When such a blend is treated with peroxide, free radicals
produced react in different ways with the two components. Both components form macromolecular free radicals when a molecule of hydrogen is abstracted from them. The macro radicals of polyethylene tend to combine with each other forming larger molecules. This leads to cross linking in polyethylene and the molecular weight increases. But macro radicals of polypropylene undergo reformation of molecular structure leading to β chain scission. This leads to degradation of polypropylene and molecular weight decreases [48].

When a mixture of polyethylene and polypropylene is treated with peroxides, reciprocal grafting reaction between the macromolecules is theoretically possible as below.

\[
\begin{align*}
\text{PE} + R^* & \rightarrow RH + \text{PE}^* \\
\text{PE}^* + \text{PE}^* & \rightarrow \text{PE} - \text{PE} \quad \text{(Cross linking)} \\
\text{PP} + R^* & \rightarrow \text{PP}^* + RH \\
2\text{PP}^* & \rightarrow \text{PP} = + \text{PP}^* \quad \text{(β - scission)} \\
\text{PE}^* + \text{PP}^* & \rightarrow \text{PE} - g - \text{PP} \quad \text{(Reciprocal grafting)} 
\end{align*}
\]

Braun et al. confirmed that in a solvent containing polyethylene, polypropylene and peroxide, the free radical reaction produced a PE - g - PP copolymer and that polyethylene cross linking and polypropylene degradation were limited. But in a process of melt blending of polyethylene and polypropylene, the free radical reaction produced cross linked polyethylene and degraded polypropylene, and there was no evidence of PE - g - PP copolymer formation [49].
1.6 PREPARATION OF REACTIVE POLYMERS

A reactive group can be incorporated into a polymer chain by –

a. Incorporation into the backbone, side chain and at chain ends as a natural result of polymerization.

b. Co polymerization of monomers containing the desired reactive groups.

c. Chemical modification of pre-formed polymer through a variety of chemical reactions.

Polymerization and co polymerization offer an unlimited number of different products by variations in the architecture of the polymer and in the nature and relative amounts of co monomer units in co polymerization, they require new processes of polymerization which are less favourable industrially. Chemical modification of pre-formed polymers especially in the melt is an attractive technique which has been used extensively in technological applications.

Chemical modification of pre-formed polymers can be conducted in solution or in melt or even in solid state. The modification of polymers during melt processing has a number of advantages – it reduces the cost of solvent removal, recovery and losses and also reduces contamination of the final product. The use of an extruder as continuous reactor / processor offers additional advantages including temperature control and pumping efficiency over a wide viscosity range and also integrates several operations into a single processing device [50 – 52].

Condensation polymers have reactive groups inherent in the backbone and at chain ends like polyamides having carboxylic acid group and / or amine end groups and amide groups in the backbone, polyesters
having carboxylic acid group and/or hydroxyl end groups and ester groups in the backbone. Some addition polymers contain potentially reactive groups in their side chains like carboxylic acid group in poly(acrylic acid), ester group in polyacrylates, double bonds in PB and EPDM. In many other cases the polymers need to be functionalized with suitable reactive groups. Various chemical reactions involved are—

1. **Free radical catalyzed grafting of maleic anhydride, AA, GMA etc onto a variety of polymers.**

2. **Substitution reactions** such as sulphonation and halogenation.

3. **Terminal modification** on both addition and condensation polymers.

Reactive polymers undergo chemical reactions seen in normal low molecular weight compounds. In polymer chemistry it is assumed that the reactivity of a functional group does not depend on the size of the molecule to which it is attached. But steric hinderance to the reaction site by the polymer backbone reduces the rate of the reaction [53]. During melt blending rate can also be reduced by the restricted diffusional mobility of the functional groups. The concentration of reactive groups used in reactive compatibilization is normally low and reaction time is short, reducing the possibility of reactive groups encountering each other in the melt for the reaction to take place. Hence to achieve successful compatibilization of polymer blends, the polymers should have sufficiently reactive functional groups; the reaction should be fast, selective and preferably irreversible; and mixing conditions should be such as to minimize mass transfer limitations to reaction. Reactions such as amidation, imidation, esterification, aminolysis, ester – ester interchange, ring opening and ionic bonding can occur at high
temperatures are used in reactive compatibilization. Isocyanate and carbodiimide groups are also highly reactive during reactive compatibilization.

Maleic anhydride MAn has been used in polymer industry to promote adhesion and dyeability. It is also used extensively in reactive compatibilization of polymer blends. MAn grafted PP, PE, EPR, EPDM, SEBS etc. have been used to compatibilise a number of blends. When used for polymer blends containing polyamides, improvement in impact strength, tensile strength, permeability, heat resistance etc. are observed. The wide use of MAn functionalized polymers is that MAn can be grafted onto many polymers at normal melt processing temperatures without homo polymerization. We can also use styrene maleic anhydride SMA or MAn copolymers with SAN, ethylene and AC as compatibilizer. MAn functionalized polymers have become highly important in plastic recycling [54].

1.7 REACTIVE EXTRUSION

Today's society and polymer industry demands new properties, lower prices and reuse of polymers. Polymers or plastics are used almost by everybody at home as well as at work. The polymers commonly used are Polyethylene (PE), Polypropylene (PP), and Polystyrene (PS) which ranges to about 25% of the polymer market. These polymers can be extruded without excessive degradation when they contain little impurities. Other commonly used plastics like Polyacetals (POM) and Polyamides (PA 6, PA 66, PA 46, PA 12 and PA 11) have more problems with degradation. Usually the mechanical properties of polymer blends are poor. However research has shown that these properties can be
brought back to their original level by adding an additional phase known as compatibilizer.

Polymers are either amorphous or semi-crystalline. A semi-crystalline polymer has an amorphous part and a crystalline part. The crystalline part has a more or less ordered structure where the chains of the polymer are often folded in a non-random fashion. The mechanical properties of semi-crystalline polymers are strongly determined by the crystallites which usually enhance their stiffness (for example PP). Amorphous polymers are either very brittle (PS) or very tough (PC). It is quite difficult to predict the mechanical properties of semi-crystalline polymers since they depend on many parameters such as % of crystallites.

The demands of many applications need a set of properties that no single polymer can fulfill. Rather than synthesizing new specialized polymer systems, we try to meet the demands by mixing two or more polymers. Mixing two or more polymers to get blends or alloys is a well established method to achieve certain physical properties. Well known examples of commercial blends are High Impact Polystyrene (HIPS) and Acrylonitrile – Butadiene – Styrene (ABS). These are tough and have good processability. However when polymers are mixed the blend is often brittle.

Mechanical properties of polymer blends are very important in many applications. Significant for these properties is compatibility between different polymers which is very often defined as miscibility of components on a molecular scale. A large number of miscible polymer pairs are known but only a few have been commercialized such as Polyphenyl ether/Polystyrene (PPE/PS), Polycarbonate/Polyethylene
terephthalate (PC/PET), Polycarbonate/Polybutylene terephthalate (PC/PBT). Other type of blend consists of incompatible polymers for which various morphologies can be realized via processing, for instance droplets or fibers in a matrix and stratified or co-continuous structures. These are usually unstable.

Melt mixing of two polymers results in blends which are normally weak and brittle. The incorporation of a dispersed phase into a matrix mostly leads to the presence of stress concentrations and weak interfaces, arising from poor mechanical coupling between phases. Improvement of mechanical properties of the blend is usually done by compatibilization which means modification of normally not miscible blends to improve miscibility. The end-use performance has been improved many fold by compatibilization.

Several methods are known to improve the properties of polymers. Many polymer additives are needed to improve the properties like processability and life time (lubricants or stabilizers), modulus and strength (mineral fillers such as chalk, clay, glass beads, mica or glass fiber reinforcement), appearance and colour (pigments), conductivity (conducting fillers like aluminium flakes or carbon) or flammability (flame retardants).

A large part of studies on blending of polymers deals with attempts to obtain a combination of properties of different polymers. But the mechanical properties of blends are usually worse instead of better for many combinations of polymers. The conventional methods for the improvement of these properties are often expensive and do not always meet the required demands. In principle compatibilization is influenced
by molecular weight distribution and concentration of the compatibilizer in the dispersed phase in complex ways to influence final blend properties. The best known effect of compatibilization is the reduction in interfacial tension in the melt. It causes an emulsifying effect which leads to an extremely fine dispersion of one phase in the other. A second effect is the increase in adhesion at phase boundaries giving improved stress transfer. A third effect is the inhibition of coalescence of the dispersed phase by modifying the phase boundary interface. These and other effects such as modification of rheology may occur simultaneously which complicates the ongoing of the whole process.

The complexity of interaction of the compatibilizer with the morphology of the blend was studied by Lester and Hope. They mixed HDPE with Nylon 6, Nylon 66, Nylon 6-3T and Polyethylene terephthalate PET with and without low levels of various proprietary compatibilizing agents. The study by SEM as well as tensile testing showed that finest dispersion of blend did not show highest values of ultimate elongation [55].

Barendsen et al. studied the compatibilization of PE/PS blend by adding (PS-g-LPDE) graft copolymer of LPDE with PS to the blends of LPDE and PS. They found that adding of 7.5% by weight copolymer caused a substantial reduction in the size of the dispersed phase [56].

It was opined by Herkens et al. that difference in the detailed fine structure of copolymers gave rise to large effects on the impact strength, and on the magnitude of the tensile modulus of the blends [57].

Nolley et al. used copolymers of propylene and ethylene (EP) displaying residual crystallinity due to long ethylene sequence as
compatibilizer for polypropylene / low density polyethylene (PP/LPDE) blends. They found that the amorphous copolymer was less effective as compatibilizing agent [58]. According to Ho and Salovey (1973), a 5% addition of ethylene-propylene rubbers (EPR) to a blend of HDPE/PP was necessary to obtain a linear relation between tensile strength and composition [59].

It must also be noted that there are many examples in the literature where blends prepared from the same types of polymer behave differently. This is due to the high sensitivity of mechanical properties to variation of temperature, composition, morphology of the blend etc.

Utracki et al. studied the influence of addition of hydrogenated poly (styrene-b-isoprene) di-block copolymer (SEB) to a blend. [60]. Paul and Barlow independently reviewed the use of block copolymers for the compatibilization of immiscible polymer blends. Addition to PET/HDPE blends variously affected the different physical properties, modulus and yield strength. Addition of block copolymers of the same chemical nature as the two homopolymers of a blend in an obvious choice which when optimized will lead to enhancement of properties [61, 62].

Shilov et al. analysed the composition of an immiscible polymer blend as a function of linear dimensions. Between a domain of polymer A and a domain of polymer B exists as interfacial layer, in some cases having a thickness up to 4nm. This interfacial region can be considered as a third phase which has been stabilized in many commercial polymer alloys through selective cross linking, resulting in reproducibility of performance, processability and recyclability. The thickness of this layer depends on thermodynamic interaction, macro molecular segment size,
concentration and phase conditions. The interfacial tension and the domain adhesion characterize the interface. The interfacial tension in the integral of the Helmholtz free energy change across the interface which gradually changes over the interfacial area from phase A to B, due to a changing composition of the third phase between both phases [63].

Mixing of two or more polymers to produce blends or alloys in a well known method for achieving a specific combination of physical properties. Mixing means break up of droplets of one polymer to obtain a dispersed phase with a very small size another polymer. This type of mixing is called blending and if the mixture formed has improved mechanical properties, it is called compounding [64].

Blending of polymers became increasingly important after Taylor studied break-up phenomena in liquids [65]. Normally, blending is used to combine the properties of two or more polymers and is performed in extruders. But the material properties are not as good as expected due to poor interfacial adhesion between the minor and major components. Hence we have to look for ways for improving the mechanical properties of such blends.

Polymers are often referred to as compatible if the mechanical properties of blends made by mixing them will have a certain set of required values. This could mean that the blend is strong enough, tough enough or ductile enough. Compatibility is often referred to as miscibility on a molecular scale. The polymer blend is compatible – if the mixture is stable under the normal conditions for its use and non-de-mixing should occur, the dispersed phase has a strong bonding to the surrounding polymer. Adhesion between both phases in a blend can be achieved by
addition of a compatibilizer. The compatibilizer is transported to the interface of the dispersed phase by means of mixing and it decreases the interfacial energy.

The morphology of the blends after blending as a function of material and processing parameters have been studied using scanning electron microscopy [66,67].

In reactive compounding chemical bonds are created across the interface. This is generally done by functionalizing one of the components with reactive groups. The method most commonly used is introduction of carboxylic acids and anhydrides on non reactive polymers by means of radically induced graft reaction. These groups react with existing reactive sites of the other component. As an alternate method, both components can be functionalized with mutually reactive sites [68, 69].

The influence of the addition of the monomer and initiator on the morphology of the blend has been investigated. The order in which the reactive media like monomers and initiators are fed during the reactive compounding in extruders is shown to have very distinct influence on the morphology of the dispersed phase and therefore on the material properties [70].

Blom et al. reported that PP & HDPE are incompatible and immiscible and that the latter caused deterioration in the elongation at break and impact strengths [71]. Yu et al. showed that in the case of gross viscosity mismatch of polymer blends, peroxides can reduce the viscosity of the PP phase by chain scission and increase the viscosity of HDPE phase by cross linking [72].
Stehling et al. as well as Choudhary et al. showed that a block copolymer of the two homo polymers in the blend can act as compatibilizer of HDPE / PP blend. They used ethylene propylene rubber as compatibilizer for HDPE / PP blends to success [73, 74].

According to Gupta et al. EVA is partially compatible with PP. Fang et al. found that EVA is partially compatible with HDPE. Blom et al. used EVA & EPDM as compatibilizer for HDPE/PP blend and found that EVA improved the impact properties of the blend while EPDM improved the tensile properties [75 – 77].

According to Blom et al. compatibilization of iPP / HDPE blend by EPDM or EVA improved the Charpy impact strength and tensile properties [78].

A significant portion of HDPE in the market finds its way into blow moulding applications like milk jugs, water jugs and detergent bottles. When attempts are made to recycle them, a problem arises due to contamination from PP. The presence of excessive amounts of PP will lead to poor mechanical properties of the recycled HDPE and it makes the manufacture of durable articles difficult [79].

Deanin and Sansone (1978), Lovinger and Williams as well as Bartlett et al. (1982) reported that the addition of PP to HDPE resulted in a decrease in impact strength and elongation at break [80 – 82].

The recycling of industrial plastics has been an ongoing practice in many industries. More recently environmental, legislative and consumer pressures have led to an increase in research directed towards the recycling of post consumer plastic waste. Industrial scrap is relatively
easy to deal with since contamination is unlikely. This is not true for municipal waste which is a mixture of several polymers which makes processing difficult and limits the number of potential applications.

A number of approaches are currently being investigated for dealing with post consumer resin PCR. A number of countries employ incinerators for the purpose of waste-to-energy recovery. Another solution is pyrolysis. Many manufacturers are introducing plastic waste into hydro crackers which convert the polymers to syncrude or naphtha used as feed stock for other applications including polymerization. Yet another approach is the redn of plastic required in articles like packages by down gauging. Many materials and goods are being reused. Lastly there is the approach of converting municipal wastes into resins which can be used to make new articles. For example, HDPE bottles for milk and water are reground and used to make oil and household chemical containers. Shopping bags are being used to make trash bags and lawn bags to collect waste.

Very often the material that emerges from a recycling facility is a blend of two or more homopolymers. This is due to several factors like not sorting the material being recycled and the fact that most articles are constructed from two or more different homopolymers.

Nearly all polymer pairs are immiscible and incompatible. This results in materials which have poor mech properties and undergo phase separation. Consequently these materials cannot be used alone or unmodified but need to be compatabilized in some way [83].

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1.8 EXTRUDER AS REACTOR

Carrying out reactions / processes with polymeric materials whose viscosities are typically in the range of 10 to 10000 Pa’s is generally not possible in conventional chemical reactors. Extruders offer some attractive features which can be used to advantage.

1. Ease of melt feed preparation
2. Excellent dispersive and distributive mixing
3. Temperature control
4. Control over residence time distribution
5. Reaction under pressure
6. Continuous processing
7. Staging
8. Unreacted monomer and by-product removal
9. Post reaction modification
10. Viscous melt discharge

But in broader application of extruders for processing we come across the following limitations.

1. Difficulty in handling large heats of reaction.
2. High cost for long reaction time.

For reactive extrusion in a single screw extruder, the basic feed is in the solid form. Reaction is unlikely to occur until the polymer has melted. The initial portions of the extruder would be devoted to solids feed
transport and melting. The requirements for this initial section are the same as for conventional compounding. After melting, contact of the polymer melt with the reactants may take place in either completely filled channels or in partially starved ones. After reaction and possibly de-volatilization, the product will likely require a pressure generation step for extrusion.

In all extruders, the melt is dragged along the barrel by the rotation of the screws. The drag mechanism is usually best visualized by unwrapping the screw flight as a continuous straight stationary channel, and sliding the barrel in relative motion diagonally over the top of the channel. As noted the extruder is also used to generate pressure to force the viscous melt through some shaping element, such as a sheet or strand die. The pressure required for extrusion also causes a back flow back down the channel. When operated starved, the flight is filled in proportion to the ratio of the actual net flow to the potential drag flow. The melt is somewhat in the form of a rolling bead. Bubbles may be present even in the absence of de-volatilization as the rolling bead induces both entrapment and rupture. Staging between starved zones can be affected by reducing the channel depth of the screw such that complete filling is assured. [84].

Hu et al. performed grafting of PP with GMA and blending with PBT in a one step extrusion. The mechanical properties of resulting blends were superior compared to the uncompatabilized blend [85].

Lovinger and Williams studied the relationship between the morphology and tensile properties of HDPE / PP blends. They found that an increase in the stress at yield and ultimate stress was related to a size
reduction of spherulites, an increase in crystallinity and the foaming of permeating network. They also reported that the ultimate elongation of all the HDPE / PP blends was lower than that of neat polymers because of the incompatibility of HDPE and PP. The tensile strength at yield increased gradually with increasing PP content.

Similar blend systems have reported different mechanical behaviour. Linear additive properties of pure PE and PP in the modulus and yield stress were observed in HDPE - PP blends by some authors, while others reported a large positive deviation or negative deviation from linearity. The synergism in the modulus and yield stress has been attributed to a reduction in the average spherulite size of PP and an increase in the overall crystallinity introduced by the addition of PE and an increase in tie molecules or intercrystalline links observed by SEM [86].

Negative deviation can be ascribed to the loss of cohesion of the immiscible inclusions in a matrix. It has also been postulated that a small amount of PE may decrease the PP matrix plasticity, and the PE has a marked reinforcing effect resulting in a delay in neck formation and hence an increase in yield stress. Elongation at break has been found to be markedly decreased for the blends compared with homopolymers. [87].

Gahleitner reported that the melt flow rate was related to the weight average molecular weight $M_w$ and molecular weight distribution (ratio $M_w / M_n$), which can influence the Charpy impact test. When $M_w$ and $M_w / M_n$ increased, the melt flow rate decreased and Charpy impact strength increased [88].
Fellahi et al. could improve the stress at break and the impact strength of mixed plastics simply by processing it in the presence of dialkyl peroxide. These improvements are like due to the formation of copolymers acting as compatibilizer by recombination of macro radicals [89].

The deleterious effect of blending on impact strength can be overcome by the creation of a microcellular structure in HDPE / PP blends. The production of a microcellular structure in the blends strongly depended on the blending conditions and the viscoelastic behaviour of the blends which controlled the cell growth and density reduction. For improved impact strength, the cell morphology had to consist of a well developed, uniform microcellular structure which was achieved by foaming at a relatively higher temperature (175°C) for a longer time (30s) with appropriate blend ratios (50 : 50 and 30 : 70 W/W HDPE/PP). The blend with highest HDPE content (70 : 30 W/W HDPE/PP) had poor morphology as the matrix was too soft, causing cell coalescence [90].

1.9 POLYMER COMPOSITES

This radically new class of materials is characterized by the marriage of quite diverse individual components that work together to produce capabilities that far exceed those of their separate elements. Their unique properties make them the enabling materials for major technological advances.

Typically, advanced materials have been characterized by a lengthy development cycle (20 years) [91]. Today the use of composite materials in structures of all kinds is accelerating rapidly in the aerospace industry
where the use of composites has directly enhanced the capability of fuel efficient aircraft in the commercial arena and new generation aircraft in the military sphere. The increasing usage of these materials is spreading worldwide, capitalizing on developments that were the direct result of a large investment in the technology over the last two or more decades.

Composites are the result of embedding high-strength, high-stiffness fibers of one material in a surrounding matrix of another material. The fibers of interest for composites are generally in the form of single fibers about the thickness of human hair or multiple fibers twisted together in the form of a yarn or tow. When properly produced, these fibers—usually of a nonmetallic material can have very high values of strength and stiffness. In addition to continuous fibers, there are also varieties of short fibers, whiskers, platelets and particulates intended for use in discontinuous reinforced composites.

Fiber-reinforced composite materials consist of fibers of high strength and modulus embedded in or bonded to a matrix with distinct interfaces (boundaries) between them. In this form, both fibers and matrix retain their physical and chemical identities, yet they produce a combination of properties that cannot be achieved with either of the constituents acting alone. The fibers are the principal load carrying members, whereas the surrounding matrix keeps them in the desired location and orientation, acts as a load transfer medium between them and protects them from environmental damaged due to elevated temperature or humidity, for example. Even though the fibers provide reinforcement for the matrix, the latter also serves a number of useful functions in a fiber-reinforcement composite material.
Fibers can be incorporated into a matrix either in continuous lengths or in discontinuous (chopped) lengths. The matrix material may be a polymer, a metal or a ceramic. Various chemical combinations, compositions, and micro structural arrangements are possible in each matrix category.

The most common form in which fiber-reinforced composites are used in structural applications is called a laminate. Laminates are obtained by stacking a number of thin layers of fibers and matrix and consolidating them to the desired thickness. Fiber orientation in each layer, as well as the stacking sequence of various layers can be controlled to generate a wide range of physical and mechanical properties for the composite laminate.

Whereas the high properties of the fibres are in part a result of their being in fiber form, as fibers they are not useful from a practical point of view. The key to taking advantage of their uniquely high properties is to embed them in a surrounding matrix of another material. The matrix acts as a support for the fibers, transports applied loads to the fibers, and is capable of being formed into useful structural shapes. The right kind of matrix can also provide ductility and toughness properties that the much more brittle fibers do not possess. The term advanced composites is used to differentiate those with high performance characteristics, generally strength and stiffness, from the simpler forms like reinforced plastic.

The development of any composite requires balancing many factors, including performance, fabrication speed and total cost. With high performance materials, the desire for improved properties is the dominant requirement. For many applications, however, better performance,
Although desirable, is not the primary need. In fact materials may already be available with properties that meet or even exceed the performance requirements. Instead the problem is to produce parts at sufficient speeds and low enough costs to obtain them cost-effectively. For lack of a better term, such composites can be called cost-performance materials.

Industry representatives believe that they must harness the chemical and physical changes that occur during fabrication to the extent that is required for the processes to be optimized and controlled. Consequently, processing science and on-line process control are key issues for the future.

1.10 COMPOSITES AND THEIR HISTORY

Modern structural composites are blends of two or more materials, one of which is composed of stiff, long fibers and, for polymeric composites, a resinous binder or matrix that holds the fibers in place. The fiber is strong and stiff relative to the matrix and generally it is orthotropic. For advanced structural composites, the fiber is long, with a length-to-diameter ratio of over 100. The strength and stiffness of the fiber are much greater perhaps multiples of those of the matrix material. When the fiber and the matrix are joined to form a composite, they both retain their individual identities and both influence the composite's final properties directly. The resulting composite consists of layers or laminas of fibers and matrix stacked in such a way as to achieve the desired properties in one or more directions.
Modern composite materials evolved from the simplest mixtures of two or more materials to obtain a property that was not there before. The bible mentions the combining of straw with mud to make bricks.

The increases in consumption of composite materials were primarily due to the need for nonconductive electrical components, noncorroding and non-corrosive storage containers and transfer lines, and sporting goods. The technologies for matrices and for the fabrication of useful structures with stronger fiber reinforcement were commercialized in the two decades after 1970. Along with the new fibers, new matrices were developed, and new commercial fabrication techniques were introduced. These developments were due in part to military aircraft designers who were quick to realize that these materials could increase the speed, maneuverability, or range of an aircraft by lowering the weight of its substructures.

1.11 ADVANTAGES OF COMPOSITES

Designers of structures have been quick to capitalize on the high strength-to-weight or modulus-to-weight ratios of composites. The advantages include

- Weight reduction (high strength or stiffness-to-weight ratio)
- Tailorable properties (strength or stiffness can be tailored to be in the load direction)
- Redundant load paths (fiber to fiber)
- Longer life (no corrosion)
- Lower manufacturing costs because of lower part count
Introduction

- Inherent damping
- Increased (or decreased) thermal or electric conductivity.

The disadvantages include

- Cost of raw materials and fabrication
- Possible weakness of transverse properties
- Weak matrix and low toughness
- Environmental degradation of matrix
- Difficulty in attaching
- Difficulty with analysis.

Generally the advantages accrue for any fiber composite combination, whereas the disadvantages are more obvious with certain combinations. Proper design and material selection can avoid many of the disadvantages.

1.12 GENERAL CHARACTERISTICS OF COMPOSITES

Many fiber-reinforced composite materials offer a combination of strength and modulus that is either comparable to or better than of many traditional metallic materials. Because of their low specific gravity, the strength/weight ratios and modulus/weight ratios of these composite materials are markedly superior to those of metallic materials. In addition, fatigue strength-to-weight ratios, as well as fatigue damage tolerances, of many composite laminates are excellent.

The properties of a fiber-reinforced composite depend strongly on the direction of measurement. For example, the tensile strength and
modulus of a unidirectionally oriented fiber-reinforced laminate are maximum when these properties are measured in the longitudinal direction of the fibers. At any other angle of measurement, these properties are lower. The minimum value is observed at 90° to the longitudinal direction. Similar angular dependence is observed for other physical and mechanical properties, such as coefficient of thermal expansion (CTE), thermal conductivity, and impact strength. Bi- or multidirectional reinforcement, either in the planar form or in the laminated construction, yields are more balanced set of properties. Although these properties are lower than the longitudinal properties of a unidirectional composite, they will represent a considerable advantage over common structural materials on a unit weight basis.

The anisotropic nature of a fiber-reinforced composite material creates a unique property for tailoring its properties according to the design requirements. This design flexibility can be utilized to selectively reinforce a structure in the directions of major stresses, increase its stiffness in a preferred direction, fabricate curved panels without any secondary forming operation, or produce structures with zero CTEs.

Most fiber-reinforced composites are elastic in their tensile stress-strain characteristics. However the heterogeneous nature of these materials provides mechanisms for high energy absorption on a microscopic scale comparable to the yielding process. Depending on the type and severity of the external loads, a composite laminate may exhibit gradual deterioration in properties but usually does not fail in a catastrophic manner.
Another unique characteristic of many fiber-reinforced composites is their high internal damping. This leads to better vibrational energy absorption within the material and results in reduced transmission of noise and vibrations to neighboring structures. The high damping capacity of composite materials can be beneficial in many automotive applications in which noise, vibration and harshness are critical issues for passenger comfort. CTEs for many fiber reinforced composites are much lower than those of metals. As a result, composite structures may exhibit a better dimensional stability over a wide temperature range. However the differences in thermal expansion between metals and composite materials may create undue thermal stresses when the materials are used in conjunction, for example near an attachment.

Many polymeric matrix composites are capable of absorbing moisture from the surrounding environment, which creates dimensional changes as well as adverse internal stresses within the material. If such behaviour is undesirable in an application, the composite surface must be protected from moisture diffusion by appropriate paints or coatings. Environmental factors that may cause degradation in the mechanical properties of some polymer matrix composites are elevated temperature, elevated fluids, ultra-violet rays. Oxidation of the matrix as well as adverse chemical reactions between the fibers and matrix are of great concern at high-temperature applications [92].

Most materials used in structural applications are polymers, metals, or ceramics, and in many present applications these materials perform satisfactorily in their unmodified or unreinforced form. In many applications where performance is the controlling factor, advanced
structural materials are needed that are stronger, stiffer, lighter in weight and more resistant to hostile environments. Unreinforced, the polymer, metal and ceramic materials available today cannot meet many of these requirements. This is especially true if the structural component must be exposed to extremely high temperatures for extended periods of time.

Natural fibers such as cotton and wool are some of the oldest materials used by early humans when strength and light weight were critical. With the development of analytical techniques such as x-ray diffraction, the reasons for the unusual properties of materials in fiber form have been understood. The molecules within fibers tend to align along the fiber axis. This preferred alignment makes the strength and modulus (stiffness) of both natural fibers and synthetic fibers superior to those of the same material in a randomly oriented bulk form. When both natural and synthetic polymers are extruded and/or drawn into fiber form, the processes of extrusion and extension orient the structure along the fiber axis. This results in high strength and increased stiffness for much the same reason that an oriented mass of strings (a rope) is stronger and stiffer than the same mass of strings with no orientation.

Unfortunately, the increased tensile strength of fibers does not come without a penalty. Fibers like rope, display this increased strength only when the load is applied parallel to the fiber axis. Even though the tensile strength parallel to the fiber axis increases as the orientation and structure become more perfect in the fiber direction, this same increase causes a decrease in strength perpendicular to the fiber axis. Also as the orientation of a fiber increases, it often becomes brittle, making it more susceptible to damage by abrasion. Thus, to take advantage of the high
strength of fibrous materials in a structure the fibers must be oriented in
the direction of the applied load and separated to prevent damage by
abrasion.

Mechanical reinforcement of matrices can also be accomplished by
using short, randomly oriented fibers, crystal whiskers or particulates.
These types of reinforcement offer directionally independent (isotropic)
reinforcement, but the degree of reinforcement is not as great as that
obtainable from longer continuous-filament fibers.

The major classes of structural composites that exist today can be
categorized as polymer matrix composites (PMCs), metal matrix
composites (MMC), ceramic matrix composites (CMC), carbon-carbon
composites (CCC), inter metallic composites and hybrid composites [93, 94].

Polymer matrix composites are the most developed class of
composite materials. They have found widespread applications as they
can be fabricated into large complex shapes and have been accepted in a
variety of aerospace and commercial applications. They are constructed of
components such as carbon or boron fibres bound together by an organic
polymer matrix. These reinforced plastics are a synergistic combination of
high-performance fibres and matrices. The fibre provides the high
strength and modulus while the matrix spread the load as well as offering
resistance to weathering and corrosion [95].

Long fibre thermoplastic composites can be divided into three
categories. The first is a family of long-and-short fibre materials suitable
for injection moulding. Typically, the reinforcement is longer than 6.3
mm but less than 25.4 mm long in the compounded pellets. This result in
injection moulded parts with fibre length distributions in the range 2 – 10 times greater than those obtained with the conventional short fibre process. The second category is a class of materials with discontinuous fibres in which the reinforcement length is at least 12.7 mm in the final moulded part. Such composites are based on chopped fibres, chopped strand mat and non-woven fibres. The third class is based on continuous fibre reinforcements, including continuous fibre non-woven as well as woven materials, preimpregnated tapes and preimpregnated or in situ impregnated continuous fibres suitable for filament winding or pultrusion processes [96].

1.13 SCOPE AND OBJECTIVES OF THE PRESENT WORK

The total consumption of plastic like polyethylenes and polypropylene has increased many fold due to their versatile nature during the last decade. A great amount of plastic waste is generated which causes environmental pollution. Due to the immiscible nature of the materials, the blend obtained by recycling the plastic waste has inferior properties – lower tensile properties and impact performance. The literature survey projects the fact that their performance can be improved by the addition of block and graft copolymers, utilization of non-bonding type of interactions, reactive compatibilization and addition of low molecular weight coupling agents. But these methods require large amounts of such reagents to be added.

The blends of commodity plastics are modified in order to upgrade their performance to the grade of engineering plastics in order to develop economically attractive replacements for engineering plastics for the use
In specific applications. In this work we propose to modify blends of HDPE & PP by adding dicumyl peroxide in order to use the blends as matrix for composite preparation. The unmodified and modified blends are proposed to be processed by reactive extrusion as well as injection moulding at two different temperatures to study the effect of the modifier, processing route and processing temperature on the blends prepared. The mechanical, flexural, impact, rheological and thermal properties of the blends are proposed to be studied in order to characterize them and the fracture surfaces are proposed to be investigated by using scanning electron microscope. The literature survey indicates that a variety of short fibre and long fibre composites have been prepared based on HDPE and PP, while the short fibre composites do not show much improvement in properties, the long fibre composites are plagued by the problem of waviness. Hence we propose to use woven nylon mats as reinforcement for developing composites based on unmodified and modified HDPE/PP blends. The mechanical, flexural, impact and thermal properties of the composites are proposed to be studied in order to characterize them. The composites prepared are proposed to be recycled and the mechanical properties of the recycled material are also proposed to be studied.

The specific objectives of this study are

1. To prepare blends of HDPE and PP and to determine their mechanical, thermal and rheological properties.

2. To upgrade the performance of such blends by modification with dicumyl peroxide and to study the mechanical, thermal and rheological properties of the modified blends.

3. To investigate the effect of different processing routes on unmodified and modified HDPE/PP blends.
4. To generate recyclable composites based on unmodified and modified HDPE/PP blends and to investigate their mechanical and thermal properties.

5. To investigate the recyclability of such composites.

1.14 REFERENCES


