CHAPTER I.
INTRODUCTION

With the advent of polymeric age in the latter part of 20th century polymers and their composites have gradually replaced traditional engineering materials such as wood, metal, glass and even ceramics in many applications because of their high strength to weight ratio, high design flexibility, ease of fabrication and relatively low cost. In addition to weight savings, composites also offer many other advantages such as resistance to fatigue and corrosion, desirable thermal expansion characteristics, thermal conductivity and damping. Because the properties of the composites can be tailor-made to meet a broad spectrum of design characteristics they have found a wide variety of applications in such area as aerospace, automotive, electronics, industrial etc.

Composites are made from two or more distinct materials that when combined are better (stronger, tougher and/or more durable) than each would be separately. The mixing of the phases is not on the atomic scale. The properties of the composites are some sort of combination of the properties of its constituents. The composite consists of one or more discontinuous phases embedded in a continuous phase. The discontinuous phase is usually harder and stronger than the continuous phase and is called reinforcement or reinforcing material, where as the continuous phase is termed as the matrix. The properties of the composite are strongly influenced by the properties of their constituent materials, their distribution and the interaction among them. To provide reinforcement the discontinuous phase must be present in a substantial volume fraction (at least about 10%).

1.1. Types of Composite Materials

The first distinction that can be made is between natural and artificial composite material. Examples of natural composites are human bone and wood.
Based on the form of structural constituents there are five general class of composites.  

1. Fiber composites composed of fibers with or without a matrix.
2. Flake composites, composed of flat flakes with or without a matrix
3. Particulate composites, composed of particles with or without a matrix
4. Filled (or skeletal) composites composed of continuous skeletal matrix filled by a second material.
5. Laminar composites composed of layer or laminar constituents.

Of all composite materials, fiber composites have evoked the most interest among engineers concerned with structural applications. Initially, most of the work was done with strong, stiff fibers of solid, circular cross section in a much weaker, more flexible matrix. The most efficient method is to combine a fibrous material of high tensile strength and high modulus of elasticity with a lightweight bulk material of lower strength and lower modulus of elasticity. In nature, the most common example of this reinforcing principle is the bamboo pole. Among synthetic materials practically every type (plastic, rubber, ceramics and metal) is now being reinforced with fibers.

The important factors that contribute to the engineering performance of a fiber-matrix composite are orientation, length, shape and composition of the fiber, mechanical properties of the matrix and the integrity of the bond between fiber and matrix. The orientation of fibers in the matrix has a strong bearing on the properties of the composite. The mechanical properties in any direction are proportional to the amount of fiber by volume oriented in that direction.

The orientation of fibers in a matrix can be accomplished by using either continuous or short fibers. Although continuous fibers are more efficiently oriented they are not necessarily better. Continuous fibers are more easy to handle but more limited in
design properties than short fibers. Cross sectional shape of the fibers is also an important parameter. Practically all fibers presently being used have circular cross section whether they are continuous or short. However, hexagonal, rectangular, polygonal, annular and irregular cross section appear to promise improved mechanical properties.

Both organic and inorganic fibers are available as reinforcing materials. The organic fibers such as cellulose, polypropylene and graphite fibers can be characterized, in general, as light weight, flexible, elastic and heat sensitive. Inorganic fibers such as glass, tungsten and ceramics can be generally described as very high in strength, heat resistance, rigidity and low in energy absorption and fatigue resistance.

The other major constituent in fiber composites, the matrix serves two very important functions. (1) It holds the fibrous phase in place, (2) under an applied force it deforms and distribute the stress to the high modulus fibrous constituent. The interfacial bond between fiber and matrix is an important factor influencing the mechanical properties and performance of composites. The interface is responsible for transmitting load from the matrix to the fibers, which contribute to the greater portion of the composite strength.

1.2. Short Fiber Composites

By using short fibers as reinforcement mixed into the rubber, one can impart drastic changes to the mechanical, thermal and viscoelastic properties of compounded rubber. These changes – even at low fiber concentrations – go far beyond the levels obtainable with the rubber industry’s traditional reinforcement, the carbon black.

Rubber finds utility in many dynamic applications to which it is ideally suited by its low bending and torsional modulus and high resilience. The reinforcement of rubber phase by short fibers
would necessarily compromise these attributes of the matrix. Too short fibers are less effective in reinforcing the low modulus materials than rigid ones. The extent to which a discontinuous fiber can approach the performance of a continuous filament or cord, depends critically upon its modulus ratio relative to that of the matrix. The continuous phase, matrix, must serve not only as a protective encapsulent or binder but also as the stress transfer medium between the applied force and the discontinuous reinforcing fibers.

Though the short fiber reinforced rubber combines the characteristics of flexible matrix and the stiffness and/or tenacity of the reinforcing fiber, short fiber reinforcement is insufficient to replace continuous cord reinforcement. However, short fibers can be incorporated directly into most of the rubbers along with other additives using standard rubber mixing equipment. The resulting product can be processed in standard rubber processing steps, economic high volume outputs are feasible. This is a significant advantage over the slow process required for the incorporation and placing of continuous fibers, cords and fabrics. Thus penalty of sacrificing noticable reinforcing strength with discontinuous fiber is counterbalanced by processing economics. In view of processing requirement it is almost mandatory to use as low a volume content of short fibers as possible and obtain improved properties. High volume content makes the compound boardy and difficult to handle in many instances. Nevertheless the improvement in mechanical properties from high volume content is important in many applications. The success of short fiber reinforcement depends on a few key requirements, these are in descending order of importance:

- Good and uniform dispersion
- Proper fiber orientation for tension
- Appropriate placement of the fiber reinforcement
- Good fiber matrix interaction: high surface area and/or adhesion
- Proper fiber choice for thermal/chemical resistance
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- Proper matrix choice for thermal/chemical resistance

Typical advantages associated with short fibers as fillers in polymer matrices include design flexibility, high low-strain modulus, anisotropy in technical properties and stiffness, good damping, ease in processing and production economy. Fibers may also improve thermochemical properties of polymer matrices to suit specific areas of applications and to reduce the cost of the fabricated articles. Moreover short fibers provide high green strength, high dimensional stability during fabrication, improved creep resistance, good ageing resistance, improved tear and impact strength and anisotropy in mechanical properties. The manufacture of complex shaped engineering articles, which is impractical from elastomers reinforced with continuous fiber can easily be accomplished with short fibers.

Foldi\(^6\) has reported the processing advantages obtained with short fiber-rubber composites. In a review, Kun\(^7\) presented effect of type of fiber, fiber pretreatment, compounding and processing on product performance properties. Zuev\(^8\) studied the mechanical properties of polymeric fiber filled rubber composites and ways of effective utilization of mechanical properties of fibers in fiber filled rubber composites and compared with those of rubber compound in the absence of fibers. Advances in short fiber pretreatment, interfacial adhesion and development of short fiber-rubber composite products were reviewed by Zhou et al.\(^9\) Fiber reinforced plastic and rubber composite electrical insulators have been manufactured by Kadowaki et al.\(^10\) The insulators useful as wire carriers comprise of fiber reinforced plastic cores, mono-pleat like rubber coverings attached on the cores and localized in between the rings. Campbell\(^11\) reviewed short fiber reinforcement of rubber.

Short fibers find application in essentially all conventional rubber compounds, examples are NR, EPDM, SBR, neoprene and nitrile rubber. Various speciality elastomers like silicone rubber, fluoro elastomer, ethylene vinyl acetate, thermoplastic elastomer and
polyurethane have also been found utility as composite matrices.\textsuperscript{12-16}

Both natural and synthetic fibers are used as short fiber reinforcement. The generally available synthetic fibers are polyester, aramid, nylon, rayon and acrylic. It is possible to improve the properties of composites by using high performance fibers such as carbon, glass or aramid. In the case of soft rubbery composites cellulose fiber has been found to give better reinforcement than glass or carbon fibers.\textsuperscript{17} This may be probably due to the fact that the flexibility of cellulose fibers results in less breakage during processing than that happens with the brittle glass or carbon fiber. A review of various types of short fibers highlighting their properties and shortcomings as reinforcements for polymers is given by Milewski.\textsuperscript{18} Various natural materials which are potential reinforcements for rubber compounds are jute,\textsuperscript{19} bagasse\textsuperscript{20,21} and pineapple leaf fiber.\textsuperscript{22} The use of asbestos, flax, glass and cotton fibers to reinforce various types of rubber is reviewed by Zuev et al.\textsuperscript{23} Manceau\textsuperscript{24} compared cellulose, glass and nylon fibers as reinforcement for SBR rubber. The use of a polyolefin based fiber as reinforcement in SBR has also been reported.\textsuperscript{25} Boustanty and Coran\textsuperscript{26} showed improved performance of hybrid composites comprising cellulose in conjunction with a chopped textile fiber. The in situ generation of plastic reinforcing fibers within an elastomeric matrix has been disclosed in literature.\textsuperscript{27,28} This method has been used by Coran and Patel\textsuperscript{29} to reinforce chlorinated polyethylene with nylon fibrils.

Derringer\textsuperscript{30} incorporated different short fibers such as rayon, nylon and glass into NR matrix to improve young's modulus of vulcanizates. Connor\textsuperscript{31} studied the processing and properties of short fiber-elastomer composites with a variety of reinforcing fibers and concluded that composite with any desired property could be obtained by manipulating factors such as fiber type, fiber content, aspect ratio, orientation, dispersion, fiber-matrix adhesion, processing methods and properties of elastomeric matrix. Investigations have been made on the feasibility of using
rubber/fiber compositions obtained from various types of waste from rubberized material and cord in the production of V-belts and tire tread compounds.  

Goodloe et al\textsuperscript{34,35} were the first to use short cellulose fibers in elastomer matrix and found that the tendency of the rubber to shrink was reduced in presence of short fibers. Short jute fiber reinforced NR composites have been studied by Murty et al.\textsuperscript{19,36} Investigations have also been made on short jute fiber reinforcement of carboxylated nitrile rubber by Chakraborty et al.\textsuperscript{37} Mukherjea\textsuperscript{38} studied the role of interface in fiber reinforced polymer composites with special reference to natural rubber. Pretreatment of jute fiber with polyesteramide polyols and silane coupling agent for improved dry and wet strength of jute fiber-polyester composites has been discussed.

Processing characteristics, anisotropic swelling and mechanical properties of short jute and short glass fiber reinforced SBR composites have been studied both in the presence and absence of carbon black by Murty et al.\textsuperscript{39} It was found that jute fibers offered good reinforcement to SBR as compared to glass fiber. Bhagwan et al.\textsuperscript{40} studied the stress relaxation of short jute fiber NBR composites.

Short silk fiber reinforced CR and NR have been described by Setua et al.\textsuperscript{41,42} Akthar\textsuperscript{43} studied short fiber reinforcement of thermoplastic blends of NR with HDPE and LDPE. Coconut fiber reinforced rubber composites have been reported by Arumugam et al.\textsuperscript{44} Effect of chemical treatment, aspect ratio, concentration of fiber and type of bonding system on the properties of NR-short sisal fiber composites were evaluated by Varghese et al.\textsuperscript{45} Dynamic mechanical properties of NR reinforced with untreated and chemically treated short sisal fibers were studied and the effect of fiber-matrix interfacial adhesion on viscoelastic properties were evaluated.\textsuperscript{46} Natural rubber-coir fiber composite was studied by Geethamma et al.\textsuperscript{47,48}
The advantage and consequences of reinforcing rubber compounds with Twaron, p-phenylene terephthalamide, short fiber and with para-aramid adhesive activated chopped fibers have been described.\textsuperscript{49} The effect of short aramid fiber reinforcement on CR rubber was studied by Park et al.\textsuperscript{50} Short aramid fiber reinforced rubber composites were prepared and the effect of fiber concentration, surface treatment and rubber type on mechanical properties of vulcanizates were determined.\textsuperscript{51} It was found that the optimum fiber concentration for reinforcement of butadiene/NR blend was \( \sim 10 \) weight percentage. The effect of surface treated short aramid fiber on CR/NBR blend was examined by Kem et al.\textsuperscript{52} and concluded that the anisotropy in tensile modulus and strength was pronounced as the fiber loading was increased. Effect of fiber loading, orientation, abrasion load and thermal ageing on the abrasion behaviour of NR reinforced with aramid short fibers were reported by Zheng et al.\textsuperscript{53}

Mechanical properties of thermoplastic polyurethane elastomer composites reinforced with short aromatic polyamide and carbon fibers were studied by Correa et al.\textsuperscript{54} Pervorsek et al.\textsuperscript{55} prepared short polyamide reinforced rubber compositions. Short polyester fiber-NR composites were studied by Senapati et al.\textsuperscript{56} and the effect of fiber concentration, orientation and L/D ratio on mechanical properties were examined. Ibarra et al.\textsuperscript{57} investigated the effect of different types of elastomeric matrices (NR, SBR, CR and nitrile rubber) and several levels of short polyester fiber on mechanical properties of uncured and cured compounds and on the swelling behaviour of composites in hydrocarbon solvent and concluded that the addition of fiber markedly reduced maximum swelling of the composites. Kutty et al.\textsuperscript{58} studied the reinforcement of millable PU with short Kevlar fiber.

Yoshiki\textsuperscript{59} reviewed characteristics of short fiber reinforced NBR composites. Stress induced crystallization and dynamic properties of NR reinforced with short syndiotactic 1,2 polybutadiene fibers and with very fine nylon 6 fibers were discussed in a review.\textsuperscript{50} Ashida\textsuperscript{61} presented a review on the type of short fibers, adhesives
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used for short fibers, the preparation and performance properties of rubber-short fiber composites.

Effect of processing parameters on the mechanical properties of short Kevlar aramid fiber-thermoplastic PU composite was reported by Kutty et al. They reported that the strength, storage and loss moduli of composites increased while tan δ_max was reduced progressively with fiber loading. For short nylon fiber SBR composites the storage modulus and loss modulus increased with fiber content and there appeared a relaxation peak in the tan δ spectra at 120 °C when the interface between SBR and nylon short fibers had good adhesion. Roy et al. reported the mechanical and dynamic mechanical properties of short carbon fiber filled styrene-isoprene-styrene block thermoplastic elastomer composites and showed that tan δ values at the Tg region decreased on filler incorporation, but at room temperature, the values increased with filler loading.

Incorporation of short poly (p-phenylene terephthalamide) in butyl rubber, NR, neoprene rubber and EPDM rubber compounds resulted in improved tensile strength, modulus, 'on-end' abrasion, thermal stability and in 30-60% lower energy loss after shock loads compared to reference compounds. The surface characteristics and the length distribution of waste short fibers from reclaimed rubber were investigated by Zhang et al. The mechanical properties of waste short fiber-rubber composites and the influence of surface treatment of waste short fiber have also been investigated.

Acrylic fiber reinforced rubber has been prepared by Moyama et al. Mechanical properties of composite materials consisting of short carbon fiber and thermoplastic elastomer have been studied by Ibarra et al. and concluded that oxidative treatment of carbon fibers exerted a beneficial influence on the properties of material reinforced with such fibers. Short fiber containing pneumatic tyres having good balance of abrasion and ice/snow-skid resistance were prepared by Midorikawa et al. Development of sealing
materials of jute fiber reinforced cork and butadiene acrylonitrile rubber was described by Xie et al.\textsuperscript{70} Kikuchi\textsuperscript{71} used nylon short fibers with 0.2-0.3 μm diameter and 100-200 μm length to reinforce NR and found that tyres made from it showed reduced weight and rolling resistance. Spherical vibrational dampers having low expansion at high temperature and good dimensional stability and shape maintenance were prepared by mixing rubbers with short fibers in their length direction.\textsuperscript{72}

1.3. Reclaimed Rubber and Its Elastomer Blends

Recycling of the used materials has been given wider attention by the environmentalists. The used rubber products and worn out tyres can also be processed and recycled to prepare reclaimed rubber which can be reused without any damage to the environment. Reclaimed rubber is the type of degraded rubber with unique properties. Reclaiming process imparts the necessary degree of plasticity to vulcanized rubber and there by enabling it to be blended with natural or synthetic rubber.\textsuperscript{73} Reclaimed rubber, unlike virgin rubber, is used in compounds to reduce the compound cost and also to improve the processing characteristics. It is cheaper than virgin rubber. It mixes faster than virgin rubber because all the fillers of the original product are already incorporated and the power consumed for mixing is less. The three dimensional nature of the rubber fragments and the reduced nerve of the reclaim imparts rate and gauge stability to the calendered and extruded stocks. But the mechanical properties of reclaimed rubber are very inferior to those of the virgin rubber due to the degradation of rubber during reclaiming. Hence it is added in small percentage to virgin rubbers.

Grant Crane et al\textsuperscript{74} reported that scrap rubber vulcanizates can be depolymerized to give a product known as ‘Depolymerized Scrap Rubber (DSR) which can be used as a rubber compounding ingredient and to extend fuel oil to yield a fuel which could be utilized in conventional boilers. Burgogne et al\textsuperscript{75} reported that mechanically ground scrap rubber having a broad spectrum of
particle size could act as a cheap filler having approximately the same effect on the properties as soft kaolin clay. According to Bleyie\textsuperscript{76} as particle size of ground rubber decreases, mixing behaviour and mechanical properties of vulcanizates are improved. Swor et al\textsuperscript{73} showed that the utilization of dry rubber reclaim in SBR improved the cure rate of SBR vulcanizates. Kazarnowicz et al\textsuperscript{77} found that blends of reclaim or ground vulcanized waste with NR had processing as well as economic advantages. Accepta et al\textsuperscript{78} showed that reclaimed rubber in the form of cryoground rubber could be bonded in a two-roll mill and compounded with common rubber ingredients. They developed a process to improve the quality of scrap rubber powder recovered from old tyres.\textsuperscript{79} Phadke et al\textsuperscript{80} reported that physical properties of reclaimed rubber vulcanizates were inferior to those of the control vulcanizate. The poor physical properties and processing characteristics could be improved by blending with fresh rubber. However high proportion of reclaimed rubber increased the stiffness and caused brittle failure. The addition of cryoground rubber caused changes in curing characteristics and showed detrimental effects on most of the vulcanizate properties.\textsuperscript{81} Higher dose of curatives and addition of reinforcing carbon black made up the losses in physical properties. Reclaimed rubber could partially replace butyl rubber in the manufacture of inner tubes for tyres.\textsuperscript{82} The presence of reclaimed rubber increased the thermal permanent strain and hardness. Magryta\textsuperscript{83} studied the processing and mechanical properties of rubber vulcanizates containing reclaimed rubber and concluded that the addition of reclaimed rubber resulted in some deterioration of mechanical properties but improved thermo-oxidative stability and decreased price of vulcanizate. Waste rubber powder (WRP)/SBR/black compound has been studied by Zhao et al.\textsuperscript{84} Addition of WRP $\leq$ 20 phr with a grain size $\leq$ 160 $\mu$m did not significantly affect the compound properties. The presence of waste rubber powder in SBR resulted in improvement in its tear strength and elongation at break.\textsuperscript{85} Modification of the rubber powder improved the mechanical properties of rubber compounds. Decrease in scorch time and maximum rheometer torque were observed when ground vulcanizates were added to SBR
compounds. It has been reported that 20% of reclaimed rubber could be used in place of NR in the blend without greatly affecting mechanical properties of the products. The use of reclaimed rubber in powder form gave rubber blends with better mechanical properties. The presence of NR latex modifiers improved mechanical properties and thermal stability of NR/reclaimed rubber blends. Cure and physical properties of EPDM vulcanizates containing ground rubber were studied with respect to particle size and amount of ground rubber by Seo et al.. The mechanical properties of rubber blends containing post consumer recycled polymer and NR, bromobutyl rubber, isobutylene rubber or EPR were examined by Theodore et al.. Gibala et al. studied the effect of black filled SBR ground vulcanizates on the tensile and trouser tear strength of rubber compounds. They reported that the compound exhibited reduced tensile strength and enhanced tear strength.

1.4. Nylon Fiber

Nylon was the first synthetic fiber to be commercialized (1939). It is a polyamide fiber derived from a diamine and a dicarboxylic acid. Because a variety of diamines and dicarboxylic acids can be produced there are very large number of polyamide materials available to prepare nylon fibers. The most common versions are nylon 6,6 and nylon 6. Nylon 6,6 which is widely used as fiber is made from adipic acid and hexamethylene diamine. The commercial production of nylon 6 begins with caprolactam. Fibers are produced commercially in various parts of the world but nylon 6,6 has been preferred in non-American markets, nylon 6 is more popular in Europe and elsewhere. The polyamide is melt spun and drawn after cooling to give the desired properties for each intended use. The fiber has outstanding durability and excellent physical properties. The features are:

- Exceptional strength
- Elasticity
- Abrasion resistance
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- Lusture
- Washability
- Resistance to damage from oil and many chemicals
- Resilience
- Colourability
- 4-4.5% moisture regain
- Smooth, soft, long lasting fibers from filament yarn
- Light weight and warm fabrics from spun yarn

Like polyester fiber, nylon has high melting point which conveys good high temperature performance. The fiber is more water sensitive than polyester. Its toughness makes it a major fiber of choice in carpets. Because of excellent tear strength it is used as a blending fiber in some cases. In certain applications the performance of nylon fiber is hard to beat. Because of its high cost it is used in specialized applications where its performance can justify the cost. Nylon fibers are used for the manufacture of splittable-pie fibers. Non-wovens developed from nylon are used in automobile products, athletic wear and conveyor belts.

1.5. Short Nylon Fiber – Elastomer Composites

Short nylon fiber-elastomer composites have been a subject of a number of investigations. Brokenbrow et al\(^9\) reported the preparation of a composite with good mechanical properties by incorporating nylon fibers in a low molecular weight non-terminally reactive liquid SBR and subsequently cross-linking it. O’ Connor\(^3\) studied the processing and properties of short fiber-elastomer composites with a variety of fibers (cellulose, nylon, glass, carbon and aramid). Effect of short nylon fibers on the mechanical properties of NR vulcanizates has been reported by Senapati et al.\(^9\) Dynamic viscoelastic properties of nylon short fiber reinforced composites were studied by Chen et al.\(^3\) They reported that the storage modulus and loss modulus increased with fiber loading. Short nylon fiber reinforced SBR compounds for V-belts applications were reported by King et al.\(^9\) Ye et al\(^9\) incorporated short nylon fibers into SBR and BR matrices and
reported that the vulcanization time increased with fiber content. Factors affecting the elastic modulus of short nylon fiber-SBR rubber composites were studied by Li et al.\textsuperscript{95} Short nylon fiber and vinylon fiber reinforced nitrile rubber and SBR were studied by Zhou et al.\textsuperscript{96} They introduced an effective interfacial thickness concept based on Halpin-Tsai equation to characterize the fiber rubber interfaces. Zhou et al.\textsuperscript{97} studied the effect of fiber pre-treatment on properties of short nylon fiber-NBR composites. The effect of short fiber pretreatment on interfacial adhesion of nylon short fiber reinforced rubber composite was studied by Zhou et al.\textsuperscript{98} using equilibrium method. Zhang et al.\textsuperscript{99} studied the influence of fiber content, pre-treatment and temperature on the rheological properties of short nylon fiber-rubber composites. The reinforcement and orientation behavior of short nylon fibers in NR, SBR and CR were studied with emphasis on the determination of ideal aspect ratio for fibers by Bhattacharya.\textsuperscript{100} Mechanical properties of nylon short fiber reinforced SBR/NR composites were studied in detail by Ma et al.\textsuperscript{101} Zhang et al.\textsuperscript{102} studied the influence of loading level of nylon fiber in NR and polyester fiber in CR and proposed a model to calculate the structure of interfacial layer. The rheological and electrical properties of NR-white filler mixtures, reinforced with short nylon 6 fiber, were studied with respect to filler loading by Saad and Younan.\textsuperscript{103} Kikuchi\textsuperscript{71} reported that tyres from nylon short fiber having 0.2-0.3 µm diameter and 100-200 µm length in proper direction and NR showed reduction in cost and rolling resistance.

1.6. Mechanics of Short Fiber Composites

In a polymer composite the fibers are stiffer than the matrix and the proportion of the load that they support is greater than their volume fraction. The overall elastic properties of a composite are relatively easy to compute from the elastic properties of the components when the fibers are continuous and parallel.\textsuperscript{104} For a perfectly aligned and properly bonded unidirectional composite the rule of mixture is applicable and is given by
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\[ \sigma_{cu} = \sigma_f V_f + \sigma_m V_m \]  

where,

- \( \sigma_{cu} \) = ultimate composite strength, \( \sigma_f \) = ultimate fiber strength, \( \sigma_m \) = matrix strength at the maximum fiber strength, \( V_f \) = volume fraction of fiber and \( V_m \) = volume fraction of matrix.

In an aligned fiber composite loaded in transverse direction, most of the deflection takes place in the soft polymer phase and the fibers do not affect the strength properties significantly.

The analysis of mechanics of short fiber composites is much more difficult than for continuous aligned fiber composites. In composites, loads are not directly applied on the fibers, but are applied to the matrix material and transferred to the fibers through the fiber ends and also through the cylindrical surface of the fiber nearer the ends. When the length of a fiber is much greater than the length over which the transfer of stress takes place, the end effects can be neglected and the fibers may be considered to be continuous. The stress on a continuous fiber can thus be assumed constant over its entire length. In the case of short fiber composites the end effect can not be neglected and the composite properties are a function of fiber length. Some corrections in the values of \( \sigma_f \) or \( V_f \) in equation 1.1 will be needed to account for the fact that a portion of the end of each finite length fiber is stressed at less than the maximum fiber stress. The adjustment depends on the length of the fibers over which the load gets transferred from the matrix.

The most widely used model describing the effect of loading in aligned short fiber composites is the shear lag model proposed by Cox.\textsuperscript{105} Rosen\textsuperscript{106} discussed the effect of fiber length on tensile properties and used the shear lag analysis to explain the mechanism of stress transfer. The average longitudinal stress on an aligned short fiber composite can be obtained by the rule of mixtures give by
\[ \sigma_c = \sigma_f V_f + \sigma_m V_m \]

where,

- \( \sigma_c \) is the average fiber stress and is a function of fiber length, \( \sigma_m \) is the matrix stress, \( V_f \) and \( V_m \) are the volume fractions of the fiber and the matrix respectively.

When the fibers are smaller than a critical length, the maximum fiber stress is less than the average fiber strength so that fibers will not fracture and the composite failure occurs when the matrix or interface fails. When the fiber length is greater than the critical length the fibers can be stressed to their average strength and fiber failure initiates when the maximum fiber stress is equal to the ultimate strength of the fibers. As the fiber length become very large compared to load transfer length the average fiber stress approaches the maximum fiber stress and the behaviour of short fiber composite approaches that of continuous fiber composites.

Abrate\textsuperscript{107} reviewed the mechanics of short fiber composites and examined the factors affecting the mechanical properties. Based on the shear lag model and characteristics of short fiber-rubber composite, Liqun et al\textsuperscript{108} put forward a new mixture law and predicted the longitudinal tensile strength of short fiber rubber composites. Fukuda et al\textsuperscript{109} described a mechanism of load transfer from matrix to fiber and predicted the young's modulus of short fiber composites. An analysis was done by Fukuda\textsuperscript{110} for predicting the stress-strain relation and strength of unidirectional short fiber composites. The classical shear lag model was modified to take into account the effect of load transfer at the fiber ends as well as plasticity of matrix material. Theories on the strength of short fiber rubber composites were reviewed by Kondo et al.\textsuperscript{111}

Derringer\textsuperscript{112} postulated certain empirical equations relating volume fraction and aspect ratio of the fibers to the tensile strength, modulus and elongation at break. The variation of physical properties of the composites with the direction of fiber orientation
was reported by Moghe.\textsuperscript{113} The effect of fiber length and orientation distribution on the strength of short fiber composite was examined\textsuperscript{114} and a general theory was formulated in terms of fiber length, orientation distribution function as well as the composite geometrical and physical properties.

The ultimate composite strength is given by

$$\sigma_{cu} = \sigma_{fu} V_f F \left(\frac{L}{L_c}\right) C_0 + \sigma_m (1-V_f)$$  \hfill 1.3

where,

- $\sigma_{cu}$ = the ultimate composite strength,
- $\sigma_{fu}$ = ultimate fiber strength,
- $V_f$ = volume fraction of fiber,
- $\sigma_m$ = matrix strength at maximum fiber stress,
- $L$ = length of the fiber,
- $L_c$ = critical fiber length and $C_0$ is the orientation parameter.

Longitudinal and transverse moduli of the aligned short fiber composites given by Halpin Tsai equation are,

$$\frac{E_L}{E_m} = \frac{1 + 2l/d \eta_L V_f}{1 - \eta_L V_f}$$ \hfill 1.4

and

$$\frac{E_T}{E_m} = \frac{1 + 2 \eta_T V_f}{1 - \eta_T V_f}$$ \hfill 1.5

where,

$$\eta_L = \frac{E_f/E_m - 1}{E_f/E_m + 2 l/d}$$ \hfill 1.6
$$\frac{E_t}{E_m} - 1 \quad \eta_T = \frac{1.7}{\frac{E_t}{E_m} + 2}$$

$E_L$ and $E_T$ are the longitudinal and transverse moduli of an aligned short fiber composite having the same aspect ratio and fiber volume fraction as the composite under consideration. The Halpin-Tsai equation predicts that the transverse modulus of an aligned short fiber composite is not influenced by the fiber aspect ratio $l/d$.

The modulus of composites containing fibers that are randomly oriented in a plane is given by

$$E_{\text{random}} = \frac{3}{8} E_L + \frac{5}{8} E_T \quad 1.8$$

Dzyura\textsuperscript{115} proposed the following expression for composite strength

$$\sigma_c = \sigma_f V_f (1 - L_i/2L) K + \sigma_m V_m \quad 1.9$$

where,

$$\sigma_c = \text{composite strength}, \quad \sigma_f = \text{strength of the fiber}, \quad V_f = \text{volume fraction of fiber}, \quad \sigma_m = \text{strength of the matrix at its maximum attainable deformation}, \quad L = \text{length of the fiber}, \quad K = \text{coefficient of fiber orientation which depends on a number of factors such as method of processing, fiber concentration, type of fiber rubber composition etc.}, \quad L_i = \text{ineffective length of the fiber and is calculated on the condition that the force required for breaking the fiber is equal to the maximum shear force on the rubber-fiber boundary},$$

$$L_i = \sigma_f d/2\Gamma \quad 1.10$$

where,

$$d = \text{diameter of the fiber} \quad \Gamma = \text{maximum shear stress on the}$$
The influence of the matrix on the value of $\sigma_c$ was reported to be dependent on its stretching resistance at the maximum composite deformation, $\sigma_m$, and not on the matrix strength, $\sigma'_m$. For composites with a higher $\sigma'_m/\sigma_m$ ratio (e.g. NR) there existed a minimum in the tensile strength-fiber concentration curve. For composites with maximum $\sigma'_m/\sigma_m$ ratio approaching unity (e.g. SBR), the minimum was not observed. The lower the value of $\sigma'_m/\sigma_m$ ratio the higher was the increase in relative strength $\sigma_c$ as compared to $\sigma_m$. Kern et al. \textsuperscript{116} presented a review dealing with different models of continuum theory for the prediction of mechanical properties of the composites.

1.7. Mechanical Properties

The mechanical properties of short fiber composites are intermediate between those containing continuous filaments or cords and particulate filled materials. Rubber reinforcement is manifested as an increase in tensile strength and modulus and a decrease in elongation and swelling in comparison to the matrix rubber.\textsuperscript{11,19} Improvements in mechanical properties in presence of short cellulose fiber,\textsuperscript{117,118} silk fiber,\textsuperscript{43,119} vinal fiber,\textsuperscript{120} nylon fiber\textsuperscript{121-124} and aramid\textsuperscript{125-127} have been reported. Coran\textsuperscript{128} developed a general relationship between fiber loading, tensile strength and elongation at break. The relationship between tensile strength and fiber loading varied from rubber to rubber. For strain crystallizing rubbers such as NR and CR, the tensile strength drops initially up to a certain volume fraction of fibers, then it increases gradually with fiber loading.\textsuperscript{56,92} For non-crystallizing rubbers such as NBR and SBR the presence of a small quantity of fiber enhances the strength.\textsuperscript{57} Murty\textsuperscript{19} reported that the strength minimum occur at low fiber concentrations because when the matrix is not restrained by enough fibers high matrix strain result at relatively low composite stresses. Once enough fibers are present to constrain the matrix the addition of more fibers.
increases the strength of the composite beyond that of the matrix alone. With excessive fiber loadings imperfections occur. The use of longer fibers move the position of the strength minimum to lower fiber concentrations, but also reduces elongation. When tested in transverse direction, strength considerably below the matrix strength may occur. Improvements in fiber-matrix bonding can improve the low transverse composite strengths. The theoretical impact of orientation of individual fibers on composite strength was reported by Schafffers. Abrate found that fibers did not break at all except when their loading was insufficient to restrain the matrix in which case large stresses could develop at low strain. Fukuda and Chou described the effect of fiber length and orientation on strength by a stochastic theory. Factors affecting the elastic modulus of short nylon fiber-SBR rubber composites were studied by Li et al and an empirical relation was derived on Halpin-Tsai equation for the prediction of elastic modulus of the composite. Liqun et al studied the law of tensile strength of short fiber reinforced rubber composites among a wide range of fiber volume and length. Zuev reviewed with 55 references on mechanical properties of polymeric fiber filled rubber composites and ways of effective utilization of mechanical properties of fibers in rubber.

Generally the tear strength of short fiber reinforced polymer composites should improve to a greater extent when the fibers are oriented perpendicular to the direction of propagation of tear in the polymer matrix than when oriented parallel to it. This has been demonstrated by several workers for short nylon 6 and PET fiber filled natural and synthetic rubber compounds. It has been reported that low fiber concentrations can elevate the tear strength of the composite above that of the matrix. However at higher concentrations, strain amplification between closely packed fibers promotes tearing parallel to the fiber direction thereby reducing tear strength. Murty et al reported that with imperfect fiber orientation or random fiber alignment, tear strength would increase as the fibers are bridging the tear. An excellent treatise was published by Kainradl and Handler dealing with the tear strength
measurements of vulcanized rubber, including the effects of specimen shape, prenotching of the sample and the thickness of the test piece. Manufacture of tear resistant short fiber reinforced conveyor belts has been reported by Hasegawa et al.\textsuperscript{132}

1.8. Factors Affecting the Properties of the Composites

1.8.1. Type and Aspect Ratio of Fiber

Aspect ratio is a major parameter that controls the fiber dispersion, fiber-matrix adhesion and optimum performance of short fiber composites. If the aspect ratio is lower than the critical aspect ratio insufficient stress will be transferred and the reinforcement will be insufficient. The fibers should be neither too long to entangle with one another and cause dispersion problems nor too short to offer insufficient stress transfer and give poor reinforcement. It is generally agreed that the aspect ratio of 150 or more is sufficient for good load transfer between fiber and matrix. Since most commercially available synthetic fibers are produced with a given set of diameter, variation in aspect ratio can be most conveniently obtained through varying the fiber length. Considerable fiber breakage occurred during mixing of fibers with high aspect ratio (as high as 500) resulting in reduction in aspect ratio.\textsuperscript{133} O'Connor\textsuperscript{31} studied the extent of fiber breakage after both processing and vulcanization and concluded that fiber breakage and distribution of fiber length occur in the uncured stock during processing and not during curing. Fiber breakage was reported in a number of other cases.\textsuperscript{36,37} For certain type of fibers like glass and carbon the fiber breakage was such that the resulting aspect ratio was too low to give good performance as reinforcement for rubber.\textsuperscript{3,134} Chakraborty et al\textsuperscript{37} have observed that an aspect ratio of 40 gave optimum reinforcement in XNBR reinforced with short jute fiber. Murty and De\textsuperscript{36,39} reported that for jute fiber filled rubbers good reinforcement could be obtained with aspect ratio of 15 and 32 for NR and SBR respectively.
Short fibers were broken during the milling process with CR so that the maximum of the length distribution shifted from 6 mm to 1.5-2 mm with short nylon, cotton and rayon fibers of diameter less than 19 μm. Noguchi et al. reported that short PET fibers did not break up during the milling process and they were well dispersed, but carbon fibers did break up during milling, the fiber length being reduced to about 150 μm. An excellent treatment on the importance of aspect ratio especially with respect to the modulus of the matrix is given by Abrate. Senapati et al. reported that fiber breakage with synthetic fibers like nylon 6 and PET during mixing into a rubber on a two roll mixing mill was negligible. A moderate breakage of short jute fibers during mixing with NR-PE thermoplastic elastomer in a Brabender plasticorder was reported by Akthar et al. Significant breakage of short kevlar fibers during mixing in Brabender plasticorder in TPU matrix was reported by Kutty et al. The effect of fiber aspect ratio on mechanical properties of reclaimed rubber composites was studied by Zhanxun et al. Varghese et al. reported that an aspect ratio in the range of 20-60 was sufficient for reinforcement for NR-short sisal fiber composites. Nagatami et al. reported that PET fibers in hydrogenated styrene-isoprene-block copolymer, resisted folding and scission during mixing and the fiber length remained unchanged. The incorporation of carbon fiber in styrene isoprene block copolymer and NR-TPE (TPNR) resulted in 30 fold reduction in aspect ratio as a result of fiber scission during the milling process. Reduction of fiber breakage of carbon fibers in CR was achieved by cement mixing method. The reinforcement and orientation behaviour of short nylon fibers in NR, SBR and CR were studied with emphasis on the determination of ideal aspect ratio for fibers. Ibarra et al. reported the drastic reduction of the aspect ratio of carbon fibers during blending in Gummix cylinder mixer. A series of short fiber reinforced SBR composites were studied by Prasanthakumar et al. with sisal fibers of different lengths and a fiber length of 6 mm was found to be optimum. The effect of fiber breakage and length on melt viscosity of sisal fiber-SBR composite was also reported. Correa reported that there was a reduction in fiber length after
incorporation of short carbon and Twaron fibers to thermoplastic PU.

1.8.2. Fiber Dispersion

The primary requirement for obtaining high performance composite is good dispersion of fibers in the matrix. Good dispersion implies there will be no clumps of fibers in the finished products. The fiber will be separated from each other during the mixing operation and surrounded by the matrix. The factors that affect fiber dispersion in polymer matrices are fiber-fiber interaction, fiber length and the nature of the fibers. It is mostly influenced by the amount of fiber. Fibers which break up during the mixing process can be incorporated at much higher levels (up to 50 phr) with ease but the resultant composite will be less effective. According to Derringer, commercially available fibers such as nylon, rayon, polyester, acrylic flock must be cut into smaller lengths of approximately 0.4 mm for better dispersion. The uniformity of fiber dispersion is best for glass, carbon and cellulose fibers. Aramid and nylon fibers tend to clump together and do not disperse easily. A pre-treatment of fibers is necessary to reduce the interaction between fiber and to increase interaction between fiber and rubber. The pre-treatments include making dispersions and formation of a soft film on the surface. Leo and Johanson described pre dispersions of chopped polyester, glass and rayon fibers in neoprene latex for better mixing in to CR or SBR rubber. It has been reported that cellulose pulp may be dispersed directly into a concentrated rubber masterbatch or into a final compound, if it is sufficiently wetted to reduce fiber to fiber hydrogen bonding. Intensive mixing has been done with cellulose fibers in an elastomer matrix. Effect of shear rate, ram pressure, fill factor, power input and mixing time on fiber dispersion were studied. Derringer recommended that organic fibers be first incorporated into a concentrated masterbatch where high shear force can be established between the aggregates. These can later be broken down to the desired compound formulation in order to optimise dispersion. The various equipments do not
produce composites with same degree of uniformity and dispersion. Goettler\textsuperscript{150} and Coran\textsuperscript{151} compared the mixing efficiency of various methods and found milling to be the best based on the properties measured though it is a slow operation. Shen and Rains\textsuperscript{149} investigated the effect of fiber dispersion on modulus and strength. They have stated a dimensionless dispersion number $N_R$, which is a function of rotor length, rotor diameter, rotor tip clearance, mixing chamber volume, rotor speed and mixing time, can be a reliable scale up parameter for short fiber mixing in polymers.

1.8.3. Fiber Orientation

The preferential orientation of fibers in the matrix is the key to the development of anisotropy in the matrix. During processing of rubber composites, the fibers tend to orient along the flow direction causing mechanical properties to vary in different directions.\textsuperscript{113} Thus by changing or suitably controlling the flow direction optimum properties can be generated for a given product. The dependence of composite properties on fiber orientation and alignment is also well documented.\textsuperscript{112,113} Milling and calendering are perhaps the most commonly used processing methods in which fibers tend to orient along the mill direction. A large shear flow during milling forces fibers to orient along mill direction.\textsuperscript{152} For a continuous flow through a fixed mill opening, all the possible fiber orientation are achieved during the first pass. Flow pattern is not expected to change during subsequent mill passes. Boustany and Coran\textsuperscript{153} reported that a high degree of fiber orientation could be achieved by repetitive folding and passing through a two-roll mill. Akthar et al\textsuperscript{43} found a small nip gap and single pass in the mill to be the best. A rubber mill was used by Foldi\textsuperscript{6} to orient various organic filaments into several types of rubber stock. Senapati et al\textsuperscript{56} reported that two passes through tight nip gave optimum mechanical properties for short PET/NR composites. The effect of mill opening and the friction ratio of the mill and temperature of the rolls on the orientation of short kevlar fibers in TPU matrix has been described by Kutty et al.\textsuperscript{62} It was observed that the lower the
nip gap, the higher the anisotropy in tensile strength, implying greater orientation of fibers. McNally has reviewed in detail the orientation of short fibers in polymer matrices.

Campbell reported that when rubber matrix containing dispersed fibers is made to flow in a non-turbulent manner, the fibers are turned and aligned in the direction of the matrix flow. Goettler et al. described the fiber orientation under different types of flow, i.e. convergent, divergent, shear and elongational and reported that fibers aligned in the direction of flow when the flow was convergent type and perpendicular to the flow direction in a divergent flow. Two passes of short nylon 6 and PET reinforced NR composites through nip of a small mill is sufficient to orient most of the fibers in the mill direction. Goettler and Lambright developed a technique for controlling fiber orientation in extrusion by the use of an expanding mandrel die. In calendering the fiber orientation occurs preferentially in the machine direction. Calendering can achieve about the same level of fiber orientation in the machine direction as conventional extrusion.

1.8.4. Fiber Matrix Adhesion

In a fiber reinforced composite the fibers carry the bulk of the applied load, the matrix serves to hold the fiber to space them, to transfer the load to individual fibers and to protect them from mechanical and chemical damage. Interfacial bonding is known to play an important role in composites. Loads are to be transferred across the fiber-matrix interface and this process affect many properties of the composite in addition to its strength and modulus. The load transfer is dependent on fiber to polymer adhesion and the fiber aspect ratio. The adhesion between low modulus polymer and high modulus fiber prevents the independent deformation of the polymer at the interface.

The improvement in reinforcement obtained by enhancing fiber-matrix adhesion through the incorporation of a bonding system has
been widely studied in the case of rubber vulcanizates.\cite{156-158} Derringer\cite{112} evaluated the HRH system with various fibers in nitrile and natural rubber and good adhesion was obtained. He concluded that the HRH system was not effective with polyester fibers in any elastomeric matrix. Foldi\cite{6} applied RFL dip on nylon fiber in NR-SBR matrix and found the reinforcing ability actually reduced. O'Connor\cite{31} compared the HRH system with RH and hexa methoxy methyl melamine (HMMM) alone in various short fiber natural fiber composites. Kondo\cite{159} reviewed the selection of adhesives for bonding short fiber reinforcements in SBR and NR compounds. Adhesion to textile fibers could be achieved with HRH system compounded into the rubber stock or by fiber treatment with either isocyanate based resins or RFL dips.\cite{160} It has been reported that the presence of tri-component bonding system (HRH) is essential for the promotion of adhesion between fiber and rubber matrix.\cite{19,37,41,42,161-163} Some researchers have found that the replacement of silica by carbon black in the tri-component bonding system leads to essentially similar adhesion level.\cite{3,164} Effect of pretreatment of fiber with polyester amide polyols and silane coupling agents on the dry and the wet strength of jute fiber-polyester composite has been studied. The mechanism of action of coupling agents to improve the fiber-matrix interface properties has been studied by Mukherjea et al.\cite{38} The role played by the HRH system in short fiber filled NR/PE blend was reported by Akthar et al.\cite{43} Arumugam et al.\cite{44} reported that HRH system was effective in improving the adhesion between coconut fiber and rubber matrix.

Kutty and Nando\cite{165} have reported that chemically treated polyester cord-NR vulcanizates exhibit lower Goodrich heat build up than untreated PET cord-NR composites. Also NR matrix compounded with HRH dry bonding agent gave lower heat generation than even chemically treated fiber-rubber composites owing to better interfacial adhesion between fiber and matrix. HRH bonding material was effective for short fiber reinforced butadiene rubber also.\cite{94} Ashida,\cite{61} in a review has mentioned about adhesives used for short fibers. Short vinal fibers pretreated with silane coupling
agents gave good adhesion with CR.\textsuperscript{120} The effect of surface treatment of nylon short fiber with RFL bonding agent was analysed for NR and EPDM rubbers.\textsuperscript{166} Owing to surface treatment, there was some improvement in mechanical properties. It was more pronounced in the case of NR than EPDM. A two-component system of resorcinol and hexamethylene tetramine was found to be better than tri-component HRH system for NR-short sisal fiber composites.\textsuperscript{45} Acetylation of sisal fiber improved the properties of the composite. The effect of addition of HRH system/RH system on the properties of short polyester fiber-reclaimed rubber composites has been reported.\textsuperscript{139} The interfacial adhesion between nylon and vinylon short fiber reinforcements treated by different methods and nitrile rubber and SBR matrix was studied by Zhou et al.\textsuperscript{96,167}

To improve adhesion between fibers and NR polyallyl acrylate was grafted on cellulose fibers by Yano et al.\textsuperscript{168} Ibarra\textsuperscript{169} used 1,4 carboxyl benzene sulfonyl diazide as adhesive agent for PET-SBR composites and obtained enhanced properties. A strong bond between PET fiber and isoprene-styrene block copolymer or butadiene-styrene block copolymer was obtained by surface treatment of the block copolymer with isocyanate in PhMe solution.\textsuperscript{170} The effect of fiber-matrix interfacial adhesion on viscoelastic properties of short sisal fiber NR composites was evaluated by Siby et al.\textsuperscript{46} The interfacial adhesion of short nylon fiber-rubber composite was strengthened by pretreating the fiber by coagulating a mix of coupling agent or adhesive, fiber and NBR/SBR latex.\textsuperscript{98} The effect of two component system (resorcinol and hexa) on NR-short sisal fiber composite was studied in detail.\textsuperscript{171} Interfacial adhesion between coir fiber and NR was improved by treating the fiber with alkali and NR solution and by incorporating HRH/RH system.\textsuperscript{47,48}

Suhara et al\textsuperscript{172} reported that in presence of HRH bonding system the water liberated during resin formation caused hydrolysis of urethane linkages and hence HRH system could not be used as interfacial bonding agent for polyurethane-short polyester fiber
composite. Effect of urethane based bonding agent on the cure and mechanical properties of short fiber-PU elastomer composites has been reported. Improvement of interfacial adhesion of poly (m-phenylene isophthalamide) short fiber-thermoplastic elastomer composite was achieved with N-alkylation of fiber surface.

1.9. Applications

Elastomers reinforced with continuous fibers are well known, but this type of composites are limited mainly to applications in tyre, belts and hoses. The manufacture of articles of complex shape can not be easily accomplished with a continuous fiber reinforced elastomer. On the other hand the preparation of intricate shaped products is possible with short fibers as reinforcements. Processing of the short fiber composites can be done by the well known extrusion and transfer moulding techniques used in the rubber industry. By adjusting parameters like fiber aspect ratio, adhesion etc. short fiber composites can replace continuous cord, as they offer flexibility in both design and processing besides imparting advantages in properties. The main application areas for short fiber composites are in hose, belting, solid tyres and pneumatic tyre components. Short fiber reinforcements in the production of hoses, V-belts, tyre tread, spindle drive wheel and complex shaped mechanical goods have been studied by many workers.

An important application that utilizes the full reinforcing potential of short fibers in a load-bearing application is as a replacement for continuous cord in rubber hose. The major advantages associated with short fiber reinforcement are easy processing, economy and higher production rate. These find applications in the automotive industry as well as for general purpose utility hoses. Using specially developed extrusion dies Goettler et al have aligned the fibers into a predominantly circumferential dispersion within the tube wall to provide the necessary burst strength. Iddon discussed an optimum screw design and extruder head construction for hose manufacturing. Schroden et al developed a high-tech hose for a high-tech car turbo engine.
Power transmission belts, more precisely V-belts, are probably the earliest practical application of rubber-fiber composites. A V-belt running over pulleys is subjected to very severe stresses when bent and flexed at a frequency of thousands of cycles per minute. Tensile stresses resulting from static tensioning and load transmission are supported by the textile reinforcing cord. The compressive sidewall pressures are supported mainly by the base rubber. The ideal material for this part of the V-belt must exhibit high modulus in the transverse direction and low modulus coupled with high flexibility in the axial direction. Such complex properties can best be achieved in an anisotropic rubber-short fiber composite. The desired transverse orientation of fibers in the base rubber can be achieved by constructing the raw V-belt from compounded sheet that was first calendered to orient the fibers and then rolled up in the 90° direction. Rogers and Yagnyatinskaya et al. discussed the use of short cellulose fiber along with polyester fibers as reinforcements for V-belt compounds. Tear resistant short fiber reinforced conveyor belts were manufactured by Arata et al. The use of CR reinforced with aramid short fiber for transmission belts have been discussed by Ichithani et al.

In tyre, chafing resistance could be improved by adding short fibers to the surface of the fabric. The apex of radial tyre has been successfully reinforced with short fibers to give it more stiffness or rather greater bending resistance. The other areas that have been identified for short fiber composite compounds in tyres are tread, belt overlay, tire inner liner and bead wrap. The use of short fibers in tire treads to improve wear characteristics has received much attention. A reduction in crack propagation rate is obtained with the addition of 1% cellulose fibers to the tread compound. Improvement in modulus and cut/crack resistance of urethane rubber was obtained with the inclusion of chopped organic fibers. Another application of short fibers in tyres involves the circumferential reinforcement of the tread to improve strength against the centrifugal forces developed according to Dubetz. Marzocchi et al. claimed improved tyre stability when a random short glass fiber mat was incorporated under the tread. Arnhem et
reported that a small amount of short fibers in the tread of a truck tyre reduced the rolling resistance considerably. Very little has been reported on the use of short fiber reinforcement in exterior panel of automobiles.

The use of fiber reinforcement in dock fenders and methods to fabricate them have been discussed by Goettler et al. Sheet roofing can benefit greatly from short fiber reinforcement. Seals and gaskets are potentially large markets for short fiber reinforcement. What short fiber reinforcement offers to seals and gaskets is excellent creep resistance, especially at elevated temperatures.

Chopped nylon fibers were used to improve the wear of crepe shoe soles. The application of cotton or other cellulosic reinforced thermoplastic polyisoprene as sheeting in shoe constructions was given by Georgieva et al. Additional applications claimed are hard roll covers, oil well packings, bearings and bushes. De and co workers investigated the potential of using carbon fibers in neoprene to shield against electromagnetic interference (EMI) and found that 30-40 phr carbon fiber loading was sufficient to make the composite a potential EMI shielding material in the electronic industry.

1.10. Scope and Objectives of the Present Work

The utilization of reclaimed rubber in rubber industry is widely practiced to reduce the compound cost and to conserve the raw material and energy. Reclaimed rubber is an effective and versatile source of hydrocarbon. It frequently improves processability and the final properties of the product. The presence of reclaim in the recipe enhances working properties in all primary processing operations. Moulding properties are often improved by the presence of reclaim in a compound. Reclaim stocks possess low thermoplasticity and are less affected by continuous milling than natural rubber stocks. For low cost applications the use of reclaim will permit a significant reduction in antioxidant. These advantages
make reclaim to substitute virgin material in rubber compound. However, there has been no systematic approach to study the various blend parameters and their effect on the blend properties. The variables that have bearing on the blend properties are the characteristics of the rubber used, the blend ratio, the compounding ingredients and processing conditions.

NR being a general purpose rubber used in a wide range of applications, it is important to know the characteristics of its blend with reclaimed rubber. The hydrocarbon content of the reclaim being 50 parts, every part of the NR replaced is compensated by two parts of the reclaimed rubber. It will be highly useful to know how the blend properties vary with blend composition.

Though the use of reclaim in a rubber compound is sure way of reducing cost, being a low molecular weight material, the presence of the reclaim in a self reinforcing material such as NR is expected to reduce the properties. It then becomes imperative to further compensate for this by using another cheap material. It will be a good idea if short fibers can be used for this purpose. Short fibers available as scrap from the fiber industry can impart improved anisotropic mechanical properties.

The properties of short fiber containing composites depend critically on fiber content, orientation and fiber-matrix interface bond strength. The detailed study of the effect of these parameters in the composite properties will be highly informative. For improved performance of a short fiber composite at a constant fiber loading, a strong fiber-matrix bond is very important. A strong interfacial bond can effectively transfer the load from the matrix to the fiber and hence can improve the overall performance of the composite. The interfacial bond is usually strengthened by using bonding agents. The knowledge of the bonding agent type, composition and optimum concentration is very much needed for proper design of short fiber composites.

The service requirements of the elastomers in different areas of
application are so wide that NR alone can not meet all of them. Of the many synthetic rubbers being used for various application, SBR and NBR are two widely used rubbers-each from a non polar and a polar group, respectively. It will be highly useful to know the optimum conditions for use of reclaim and short fibers in these matrices as well. It calls for a study in the case of these two elastomers as in the case of NR.

1.1. References

Introduction

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