STANDARDIZATION OF FRICTION CORDS AND ITS APPLICATION IN RUBBER FORMULATION TECHNOLOGY

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DECLARATION

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Abstract

Dramatic growth in both the use and manufacturing of pneumatic tires including car, bus, truck and airplane tires have led to the accumulation of calendering scraps referred to as unvulcanized rubber friction in junkyards where they pose a fire threat and breeding sites for animals including rodents and insects spreading various diseases. These scraps appeared in bulky nature were subjected to a size reduction process in order to produce friction cords. Since calender scraps cannot undergo natural degradation, piling up of them causes definitely a huge environmental problem. Environment is benefited greatly by reusing these materials as friction cords. Additionally, rubber products manufacturers use friction cords in blends by incorporating them into their rubber compounds. Friction cords are manufactured from leftover materials and as a result they are definitely a cheap product at the market. This results in lowering the final cost of products manufactured by blending friction cords. Six samples of friction cords collected from each bulky material were tested for basic physical properties including specific gravity, hardness, tensile strength, elongation at break, moisture content and rheological properties such as t_{s2}, t_{c90}, M_L and M_H. Results obtained showed that each and every property of each bulky material varied and that variation occurred from one material to the other. Therefore the main objective of this study was to standardize friction cords by physically mixing one material with the other in different weight proportions. Results obtained for each blend/mixer showed that all tested properties including specific gravity, hardness, tensile strength, elongation at break and moisture content could be controlled within the required range and it was concluded that friction cords can be standardized by mixing them at different weight ratios. In addition, variation in rheological, physical and mechanical properties of fiber filled rubber compounds were studied by replacing nylon flocks partially and completely with friction cords. Results obtained showed that minimum torque, scorch time (t_{10}), optimum cure time (t_{c90}) decreased with the addition of increased quantity of friction cords. However, maximum torque increased with increased loading of friction cords. There was no significant change in specific gravity and elongation at break. But hardness modulus at 100 % elongation, tensile strength gradually increased with the addition of friction cords.

Keywords:

Friction cords, short fibers, standardization, rheological, physical and mechanical properties

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1. INTRODUCTION

With the development of rubber industry, polymer materials are discarded as waste in large quantities in the world every year [1]. In rubber industry, fabric scraps/calender scraps piled up at the calender lines can be considered the one of waste rubbers generated during the manufacturing of pneumatic tires. In one hand, these materials cannot return to the ecological environment through natural degradation process [1] and on the other hand, disposal by landfill or by incineration brings about a lot of negative effects on the environment [2]. Piling up of fabric scraps being kept increasing day by day is a serious environmental problem. Therefore, recycling of this type of rubber waste materials has become a growing importance for all countries in the world in the recent years. Since scrap tires have already been undergone vulcanization process, technologies like reclaiming, devulcanization, grinding and pulverization are commonly used for recycling of them [3]. But fabric scraps are in unvulcanized state and consequently they are known as unvulcanized rubber friction. US Lanka Rubber Solutions Private Limited in Seeduwa is the sole plant involved in recycling of these unvulcanized rubber frictions. In recycling, unvulcanized rubber friction which appears in bulky form is subjected to size reduction process at different stages in a production line until the final product/friction cords is obtained.

A friction cord which is also known as fiber reinforced compound (FRC) is a semi-finished rubber product and is quite a new and useful material in rubber industry. Tire manufacturers have used to apply FRC in base layer or heal component of solid tires as it is a huge cost saving for their final product. And recently, it is considered the most successful application of FRC.As in the case of scrap tires, FRC is considered to be a “rich material” [2] because of its composition and properties. FRC usually appears in granular form and consists of randomly distributed short fibers such as rayon, nylon, polyester and aramid and etc in rubber matrix. As the name implies, reinforcement in FRC is due to the random dispersion of these short fibers. However, reinforcement is far below than that in the continuous

cord reinforced composites. Lack of fiber orientation and inconsistency in each and every ingredients present in rubber matrix has resulted in variation of all physical properties of FRC. Variation in properties within the whole bulky material, from material to material and batch to batch variation in properties are the major disadvantages associated with FRC. Due to this reason rubber products manufacturers find always practical difficulties in applying FRC for their products.

FRC consisting of two separate phases such as a reinforcing phase and a matrix phase can expected to be similar to short fiber-rubber composites. But the randomly distributed fibers and variety of compounding ingredients along with different rubbers present in matrix phase individually and collectively determine the final properties of FRC. In literature, a large number of publications on properties and applications of short fiber-rubber composites can be found. The tensile strength, tensile modulus, flexural strength, flexural modulus got increased with the increase in fiber content in a composite based on a polystyrene and natural rubber [4]. Further, it has been evaluated the effects of fiber orientation and anisotropy on tensile properties of two short glass fiber reinforced thermoplastics and it was found that tensile strength and elastic modulus significantly drop from in-flow direction to perpendicular-to-flow direction at all temperatures and strain rates [5]. Most fiber types used show a reinforcing effect in accordance to the respective fiber properties and use of coupling agent show that fiber/matrix interaction has a significant impact on short-fiber-reinforced polypropylene composites [6]. However, there is no any experiment or publication on FRC done up to now. Therefore this study covers the characterization and standardization of FRC and at the end, how FRC effects on properties of the filled rubber compounds were also studied.

2. OBJECTIVES

a) Standardization of Friction Cords

Different weight proportions of FRC were mixed physically to prepare blends in order to determine whether standardization using this mixing technique is feasible or not.

b) Selecting parameters for friction cord character

In characterization, friction cord samples were tested for rheological properties and basic physical properties including specific gravity, hardness, tensile strength, elongation at break and moisture content.

c) Effect of friction cord on properties of rubber compound

Rheological characteristics such as minimum torque, maximum torque, scorch time (t_{10}), cure time (t_{90}) and physical and mechanical properties including specific gravity, hardness, elasticity modulus at 100 % elongation, tensile strength and elongation at break of compounds filled with friction cord were tested in order to determine the effect of friction cord on properties of rubber compound.

3. LITERATURE REVIEW

3.1. Origin of Friction Cords.

Today the growth of global tire production has been in response to the growth in the automotive industry and tire consumption around the world. Tire is a complex engineering structure [2] which is designed to be used in wide range of environmental conditions. There are two main types of rubber tires, such as: (1) Solid tires or cushion tires. (2) Pneumatic tires or air filled tires. Solid tires are made entirely of rubber fitted directly to the rim or wheel. The main functions of this rubber portion are to carry the load, absorb shocks, and resist cutting and abrasion. Nowadays solid tires are being used in off-the-road applications including industrial and farm carts, military vehicles, where there is a tendency of tires being pierced. On the other hand, pneumatic tires are used for almost all the free-moving vehicles such as automobiles, trucks, buses, bicycles, three wheelers, airplanes and etc. Unlike a solid tire, a pneumatic tire has no ability in itself to carry load and absorb shocks. But those functions are carried out mainly by the compressed air that fills the tire.

The prime factors of consideration in manufacturing of any kind of tire are its quality and performance requirement of the customer [7].Tires consist of variety components which are not identical in composition and properties [8]. Each component has its specific properties and functions individually to contribute to the overall performance of the tire [8]. Therefore, even a minor error occurred during at any production stage, if it is ignored, would drop the final quality of tire, which in turn would affect the safety of the end user. In a tire manufacturing plant, all the components of a tire is prepared using three main processes, namely, extrusion, calendering and bead building. Any component which does not meet the required specifications has to be discarded in order to achieve a good quality in the finished tire.

As it has been described above, in tire building, component preparation can be divided into three main classes such as extrusion, calendering and

bead building. In this study, process of calendering is greater concerned because, uncured (uncross-linked) fabric scraps, the major source of manufacturing friction cords usually originates at this stage on a daily basis in a pneumatic tire plant. Products like tires which require high surface quality and double coated fabric cords usually use 4 roll calenders [9]. Additionally, calendering operation needs critical checks to ensure that high quality products are obtained. Thickness is the one of main factors affecting the final quality of calendered sheets and the thickness should be uniform in both the machine and cross-machine direction [9]. Any variation in gap size due to roll dimensions, settings, thermal effects, and roll distortion resulted from high pressures developed in the gap finally lead to the non-uniformity in thickness of the sheet [9]. In addition, spacing between cords, the number of cords (refer to as EPI or ends per inch), the penetration of rubber into the composite sheet and adhesion of rubber to the fabric or steel cord are also critical to final performance. Furthermore, the tire engineer usually considers the following factors of a tire textile in obtaining a good quality calendered sheet [7].

1. Chemical composition of textile.
2. Cost per unit length and weight.
3. Denier - filament size and strength.
4. Cord construction - number of yarn plies.
5. Cord twist.
6. Number of cords per unit length in ply.
7. Number of plies in the tire.

When required specifications of calender sheets for a particular tire application are not met, it appears as defects on calender sheets and those are rejected at calender lines. As it has been depicted in figure 1.0, squeegee wrinkle, ply wrinkle, bare patches, bad edges and defects due to over pressing are the various types of defects that cause low quality of finished calender sheets (A collection of defects on calender sheets from US Lanka Rubber Solutions Private Limited, Seeduwa).

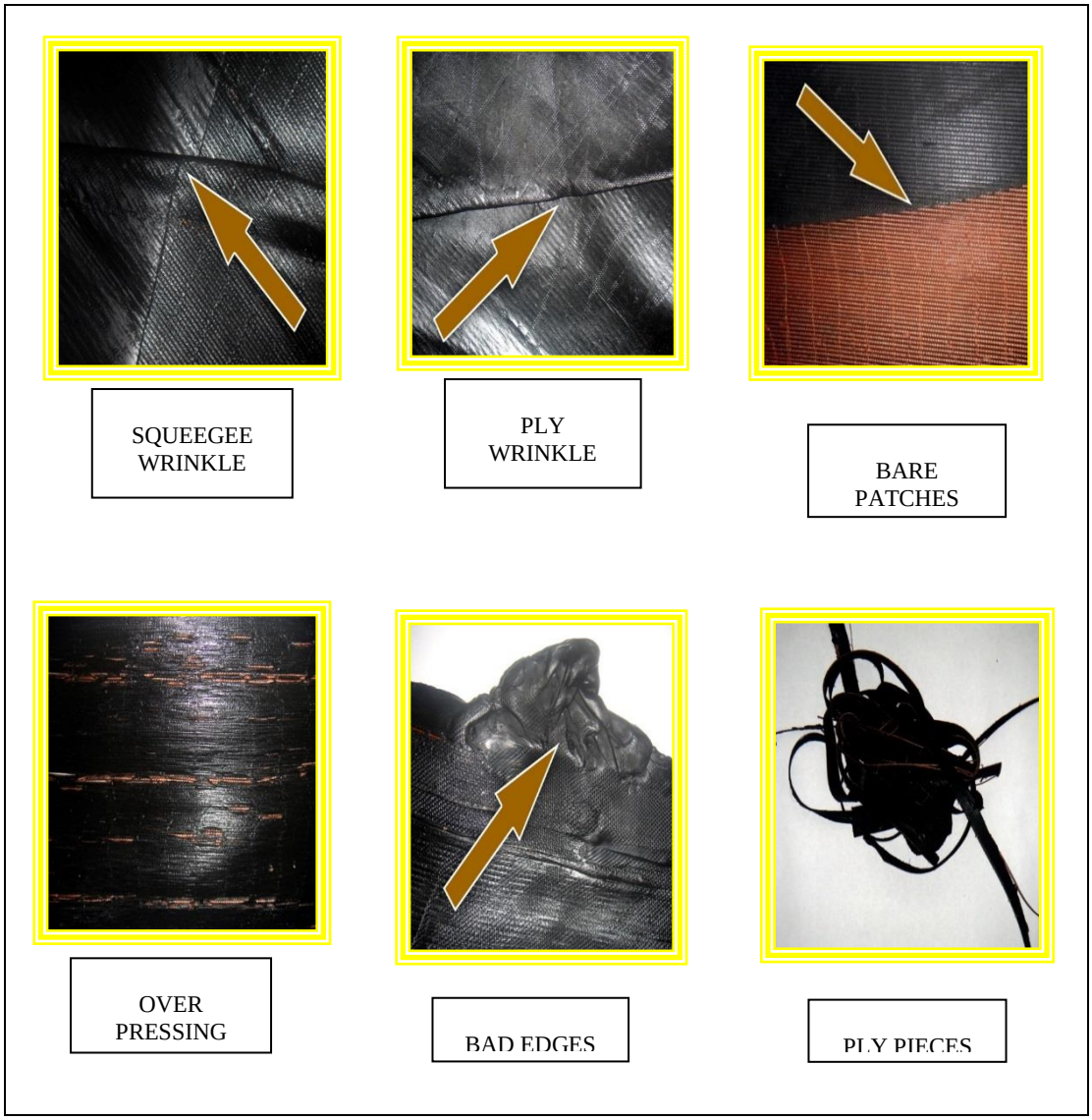


Figure 1.0 Defects on calendar sheets

With the increase in rate of production of tires, rate of generation of scraps are expected to be high and these scraps are get collected one by one on top of the other at the calender line. In addition to fabric/textile scraps (rejected calendared sheets with fabric cords), bead scraps, compound scraps can also be found tire plants. Currently, a large heap of rubber waste materials has posed a major threat in maintaining a clean environment on the earth [1, 2, 3, 10]. Practically, it is difficult to expect zero wastage at any time at any production stage but this wastage can be minimized to a certain level by careful handling of materials and equipment.

Therefore, recycling and reusing of these waste materials would be a greatest remedy for this environmental suffering.

3.2. Effects of Rubber Wastes on the Environment.

With the advancement in rubber industry, manufacturing and use of rubber related items around the world are increasing day by day [10]. Tires for the automobile industry represent the larger portion of usage of rubber [10]. Worldwide growth of automobile industry and increasing use of car as the main method of transport push upwards the rate of production of tires [11]. This has created a huge stockpile of scrap tires in major tire manufacturing countries [11]. These scrap tires represent the major type of post-consumer or retired products, generated at the end of life [12]. Whereas scraps generated in calender lines in tire manufacturing plants are considered the greatest portion of waste materials collected during manufacturing. Therefore, in general, generation of rubber waste materials occurs at main two stages, such as: (1) at the stages of manufacturing. (2) at the end of life. Whatever the type of scraps generated, first and most important one is to protect the environment using an appropriate recycling technique.

3.2. a. Effects on the environment by scrap tires.

The increased use of rubber in tires, results in growing volume of scrap tires [2, 11]. Usually, more than 242 million of scrap tires are generated per year in the United States [10] and in Japan it is about one million tons per annum [6]. Whereas over hundred thousand tons of used tires are disposed annually in Taiwan and this figure is increasing [11]. With the tremendous growth in stockpiles of rubber scrap tires, a larger space for storage has become a necessity. Moreover environmental problems caused by piling up of scrap tires are immense. Consequently, a significant attention is being given in recent years on new techniques for disposal and recycling of waste tires [1, 11]. There are a large number of publications in the literature regarding the harmful effects on environment caused by inefficient methods of disposal of used tires. Even though landfill is one of the

earliest methods of disposing used tires, it has now been realized by many countries in the world that landfilling is no longer feasible as it creates a lot of environmental problems [2, 10, 11, 13]. Scrap tires used for landfilling tend to settle unevenly and to float on top [10, 13, 14]. Shape, impermeability and indestructability nature of used tires permit it to collect water for a long period of time which in turn provide breeding sites for mosquitoes [1, 2, 3, 13], pests and other animals including mice, rodents and snakes [2, 3, 11]. These species, especially the mosquitoes may spread deadly diseases such as dengue, chikungunya and malaria [1, 2, 3]. In the case of fire, the atmosphere is get polluted by the emissions of various toxic gases and dense black smoke which results in poor visibility [2]. In addition to this, the soil is also affected as leaching of metals and small molecular weight additives such as stabilizers, flame retardants, colourants and plasticizers from the bulk of scraps to the surface and from surface to the soil; leaching of these materials are not eco-friendly as these materials kill useful bacteria in the soil [2, 10, 13]. Ultimately the soil may lose its essential nutrients. Since scraps tires cannot be subjected to decomposition, burying waste tires makes the service life of burial ground short and eventually it may give low economic benefits [11].

3.2. b. Effects on the environment by scraps of calendered textile cords and steel cords.

In proportion to the increase in quantities of scrap tires, there is a great demand for new tires. As a result of this, tire manufactures around the world are aiming at fulfilling this demand by competitively increasing their production rates. Increased production rate in one hand fulfill this great demand for tires and it on the other hand leads to the generation of scraps in huge quantities. Calendered plies being applied in the major part of a pneumatic tire, namely the carcass, consisting of body plies and belts [3, 7], are produced in large quantities. Bridgestone, Michelin, Goodyear, Continental and Pirelli are the leading pneumatic tire manufacturers in the world [15] and the global production of tires is about 1.4 billion unit per annum [2]. In proportion to global production of tires, calender sheets with defects are get rejected and piled up day by day. Therefore, stockpiles of

these scraps require a vast area for storage due to their large volume and it is evident from the Figure 1.1. Samjay and Sons, LLC, Ohio, USA, categorized under wholesale scrap rubber company reports that annual scrap rubber generation in USA is about 8 million lbs and there is a 5-10% scraps generation from the annual global tire production.

Figure 1.1 Calendered scraps

Living organisms like animals and plants can undergo processes such as decomposition, biological degradation and hydrolyzation which are needed in maintaining ecological balance [1]. They belong to the class of environmental materials and they are having superior properties and best environmental compatibility [1]. More than one hundred million tons of polymer materials including calender scraps are discarded as waste every year worldwide [1]. Since these polymer waste materials cannot return to the ecological environment through natural degradation and decomposition processes, they are categorized under non-environmental materials [1]. In the section 3.2.a, environmental pollution caused by disposal of waste tires was discussed in greater details. Even though there is a large body of literature addressing the environmental threat associated with scrap tires, recycling techniques and their applications, literature on effects of tire calendering scraps on the environment and recycling techniques associated with them could not be seen. However, rejected calendered cords create the same environment sufferings, as in the case of scrap tires, because of its large shape, impermeability, inability to be destroyed and decomposed, if they are used for landfilling. Samjay and Sons,

LLC, Ohio, USA states that landfilling of these calender scraps are completely prohibited in USA and other countries around the world and instead recycling and selling of these solid waste materials to companies who use rubber for some other type of rubber products are encouraged. Therefore it is a timely necessity to find a proper recycling technique to minimize these effects on environment.

3.3 Manufacturing of Friction Cords.

According to Samjay and Sons, LLC, USA, renowned companies in the world for manufacturing of FRC are the De Ruijter International B.V., Netherlands and ETS Simonis S.s.a., Belgium. Today, US Lanka Rubber Solutions Private Limited, Seeduwa is a newly established company producing FRC only, is considered to be the sole manufacturer of FRC in Sri Lanka. All the information relevant to the manufacturing of FRC were taken from the document, Standard Practice for manufacturing of FRC in US Lanka Rubber Solutions Private Limited. In a large tire manufacturing plant, a large variety of tires are manufactured at the same time. Scraps generated at the calender lines get piled up continuously and ultimately all those scraps appear as a heavy chunky (bulky) material on the production floor. These scraps consist of steel cords and fabric cords coated with rubber compound which are used to construct the carcass [3], the framework, the most important part of a tire. Use of steel cord calendering scraps for the production of FRC, typically requires that steel cords/wires be removed. As it can be seen on the literature, removal of steel wires is a must in order to recycle tires also, but it is currently a costly process [16]. However, if the steel cords are removed by using an appropriate technique, only the compound part will remain. Separated compound, free of steel cords does not satisfy the property requirements. But steel cord compound can be mixed together with other raw materials consisting of textile fibers, to produce FRC. Due to these difficulties, steel cord calendering scraps are not considered in this study as a source of manufacturing of FRC. Instead, fabric cord calendering scraps are concerned as the major source. Moreover it is an important quality requirement that all fabric scraps should be in unvulcanized state, because vulcanization makes the rubber definitely insoluble in any solvent, infusible

thermoset material and it never can be processed further by any method which requires flow properties such as in a mixer, in an extruder, on a mill, on a calender and etc [2, 17].

Step 1:

The first step of manufacturing of FRC is to clean the scraps or raw materials by removing dust and other waste materials including metal wires/pieces, plastic pieces, polyethylene, stones, wood pieces, papers and etc. Further, visual inspection throughout the process to remove any kind of impurity, is a key requirement to ensure good quality product. Since these raw materials are the scraps from pneumatic tire plants, most of them are with various impurities (Figure 1.2). Presence of these materials in FRC will lead to poor adhesion or poor bonding between layers in the applied product, because of the loss of compatibility of these stuffs with FRC and the compound of applied product. As a result of poor adhesion a lot of cracks are created between layers and eventually the physical properties of the final product gets drop.

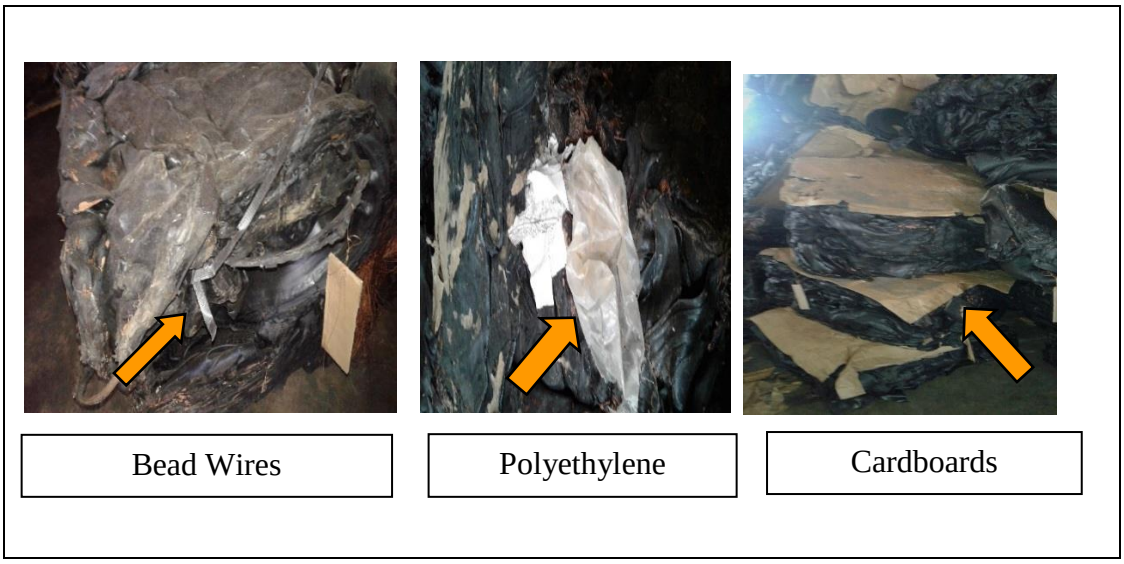


Figure 1.2 Impurities on bulky raw materials

Step 2:

XQL-16 type hydraulic rubber cutter equipped with hydraulic power pack and double acting hydraulic cylinder is used to cut bulky raw material of varying sizes (100kg – 2000 kg). Inclined cutters are fed with raw materials continuously using rollers and then steel alloy blade is used to cut these materials into large pieces of 1kg-5 kg (Figure 1.3). Two skilled operators operate the machine, carry the pieces of materials out from the machine and keep them on pallets. At this stage, all materials are visually inspected in order to remove impurities like pieces of plastics, cardboards, papers, polyethylene and etc.

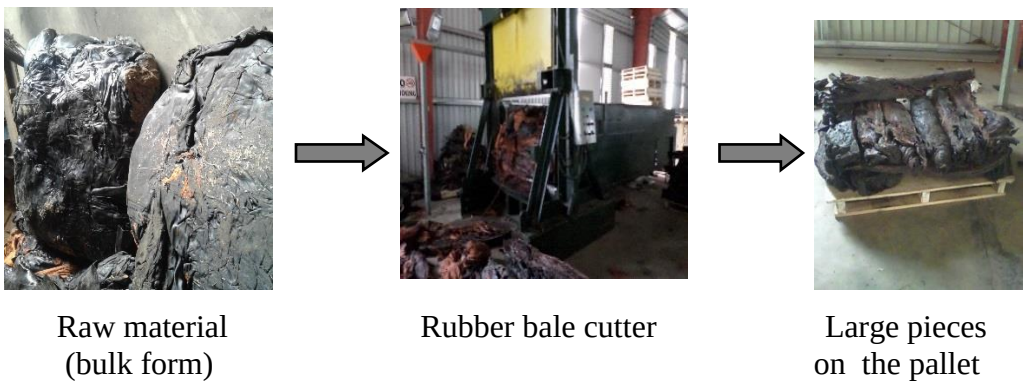


Figure 1.3 cutting raw materials into large pieces

Step 3:

Guillotine rubber cutter consisting of rubber knife, frame, cylinder, base, auxiliary table, hydraulic system, and electric system is used to cut large pieces of raw materials into small sized pieces of about 250 g- 350 g. When cutting the raw material, put it under the rubber knife, then press the start button, the knife cuts the materials. Rollers provided with the machine are used for easy handling of rubber pieces (Figure 1.4). Impurities are removed by visual inspection, if they are further present on materials.

Large pieces from Step 2 | Guillotine rubber cutter | Small sized pieces

Figure 1.4 Cutting large pieces of raw materials into small pieces

Step 4:

Pieces of raw materials having weights of 250 g-350 g (output from the Step 3) are fed through a metal detector into a SML 60/100-G3-2 type granulator(Capacity: 700-1600 kg/hour),30x38" opening, very large feed hopper with hydraulic opening, 4 knife open rotor with two bed knives. Metal detector detects metal/steel pieces present in raw material and those are rejected at this stage before feeding them into the granulator via a conveyor. Rotary knives pull the material into the cutting area and disintegrate the slabs to a size fine enough to pass

Small pieces of raw material from Step 3 | Granulator | FRC (Granular form)

Figure 1.5 Cutting small pieces of raw materials into FRC granules

through a special sizing screen. Since granulator screens (Figure 1.6) with different hole sizes like 10 mm, 25 mm and 35 mm are fitted inside, FRC granules of cord lengths 10mm, 25 mm and 35 mm can be obtained. But one type of screen can be fitted at a time to obtain the required length of granules (Figure 1.5). Temperature of the output (FRC) is maintained well below 70 ^{0}C. The granulator is equipped with a conveyor belt for carrying the output (FRC) to the drying area where the product is kept lying until the temperature of it reaches up to about 40 ^{0}C. Impurities like pieces of papers, cardboards and etc are manually picked up and removed at the conveyor belt. Furthermore, a metal detector is fitted onto the conveyor belt to detect any metallic pieces in the product and those are removed.

Figure 1.6 Granulator screen

Step 5:

Once the temperature reaches up to about 40 ^{0}C, the product is put into polyethylene bags or pressed into bale form using a bale press machine (Figure 1.7). Since raw materials are in uncured state, temperature has a big role to play in the processing of them. Therefore, temperature of the output at the granulator is maintained at below 70 ^{0}C and at below 40 ^{0}C before putting them into polyethylene bags. The product tends to get scorched or partially cured during storage, if the temperature of it is ignored, because there is a greater possibility to build up heat inside bags and bales. As in the case of manufacturing of tires, there is no any complex processes such as compounding and mixing which require some expensive chemicals. The whole process of manufacturing FRC involves only a few number of stages during which the scraps undergo size reduction processes only from its staring point to end point

where the final product is obtained. Consequently, the process is not very complicated and the relevant process flow chart is shown in figure 1.8. In addition, whole manufacturing process contributes to zero wastage and hence this can be considered an environmental friendly process.

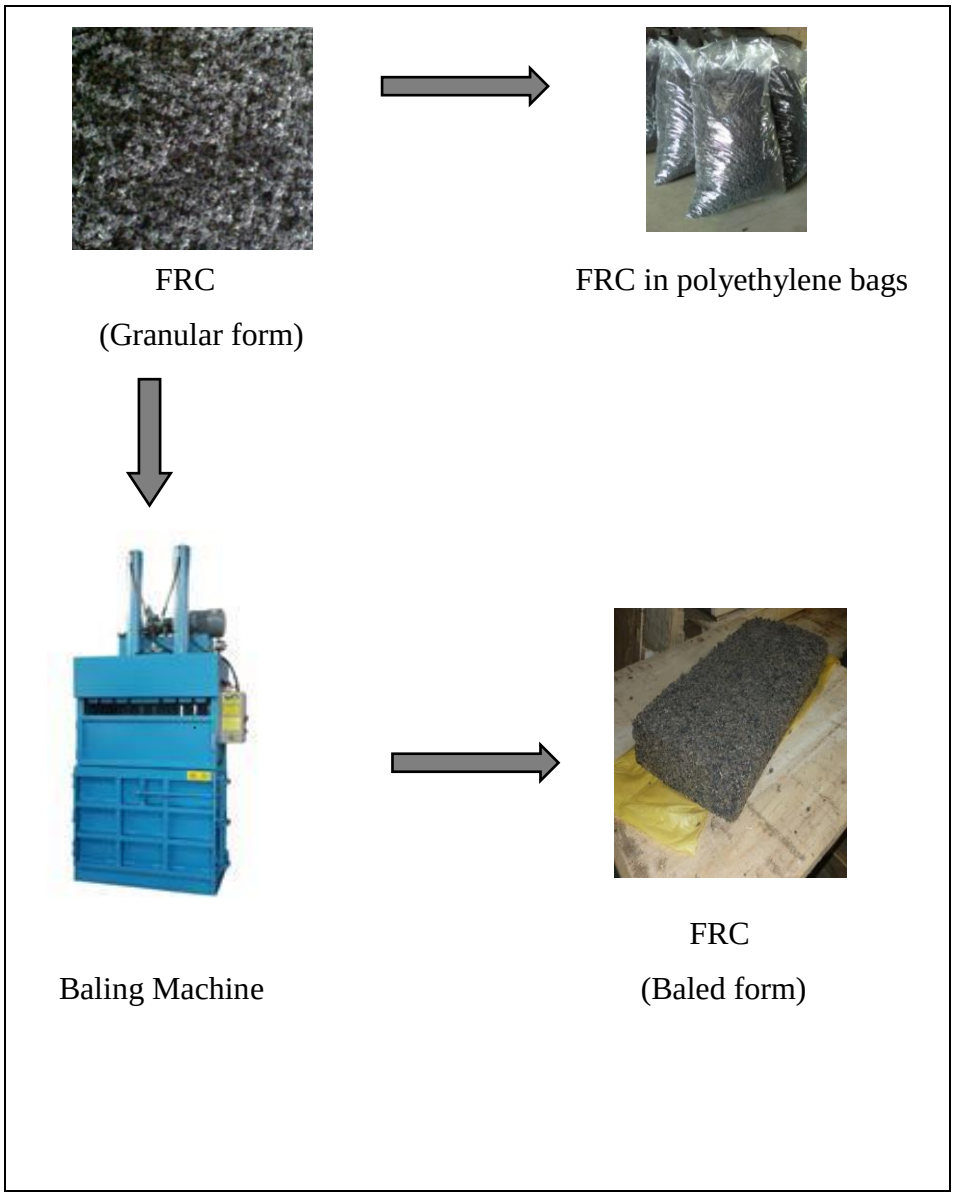


Figure 1.7 Packing of FRC

Manufacturing of FRC

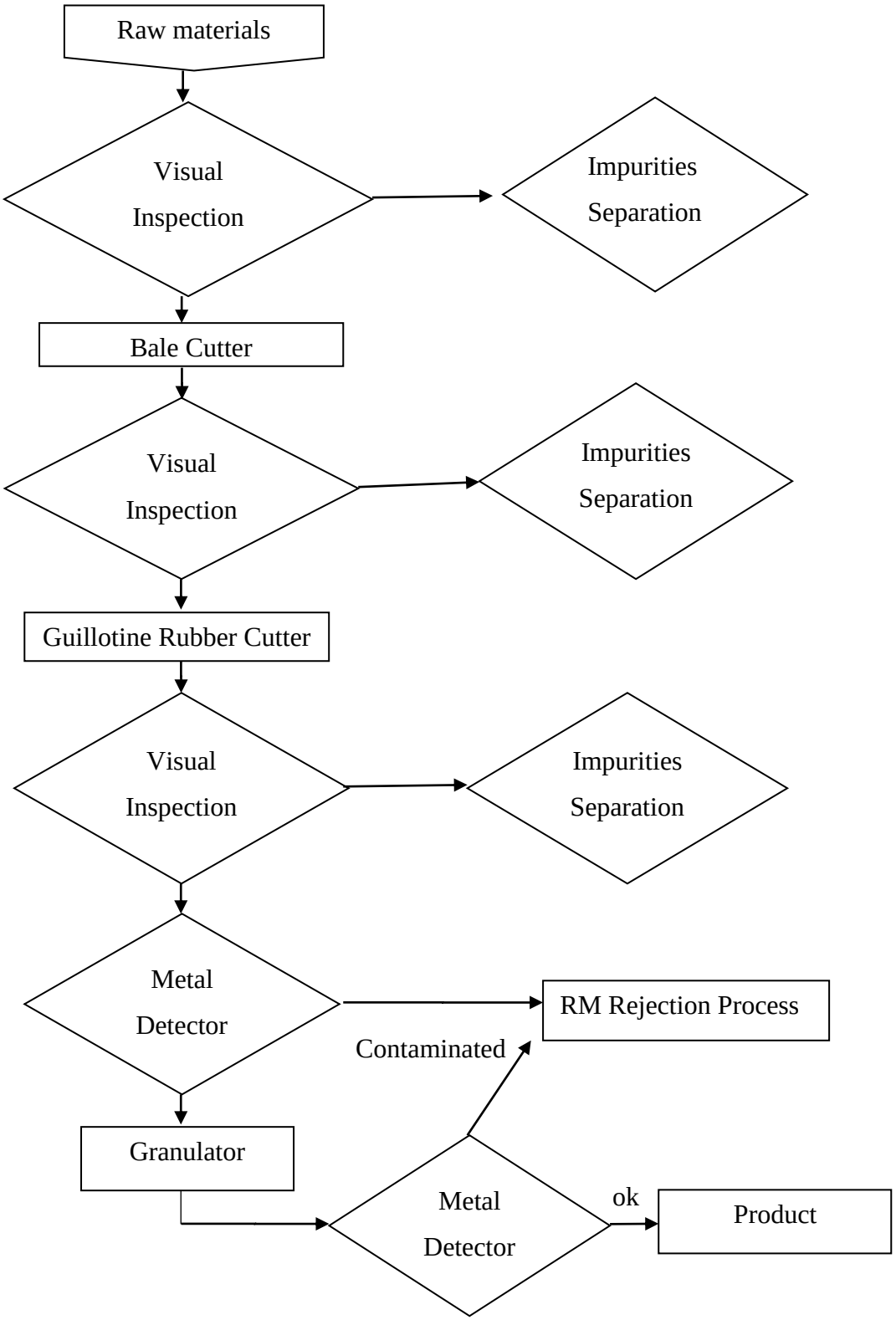


Figure 1.8 Process Flow Chart

3.4 Properties of Friction Cords.

Calender scraps/fabric scraps which are used as raw materials for manufacturing FRC are in bulk form. According to the stock reports of US Lanka Rubber Solutions Private Limited, weights of these bulky materials vary from 100kg – 2000kg. Furthermore, these materials are also known as unvulcanized rubber friction, because the materials are in uncured /unvulcanized state. From time to time people in tire industry have used different types of fibers/textiles such as cotton, polyester, rayon, nylon, fiber glass, aramid (Kevlar) and steel [7, 16] in tire building and all of them are embedded in rubber matrix of unvulcanized rubber friction. In other words, all calender scraps which are in uncured state and consisting of fibers such as nylon, rayon, polyester, Kevlar, cotton and etc belong to the category unvulcanized rubber friction .Therefore, following categories, depending on the type of fibers, can be found among the stockpiles of scraps.

1. Rubberized nylon friction

Due to excellent fiber properties of nylons (polyamids), nylon 6 and nylon 66 have become the most successful application especially, as the tire reinforcement cords [7, 18]. Therefore rubberized nylon friction (Figure 1.9) can frequently be found in stockpiles of calender scraps.

Figure 1.9 Rubberized nylon friction

2. Rubberized Textile Cord friction

Even though nylons are more popular among tire manufacturers, the amount of reinforcing steel or synthetic fibers used in rubber tires usually varies from one manufacturer to the other. Consequently, there are some manufacturers who use the average composition of reinforcing fibers as given below [16].

Rayon : 2.8 %
Nylon : 1.3 %
Polyester : 0.1 %
Steel : 13.1 %

It is obvious from this composition that textile fibers like rayon, polyester other than nylons are used in tire applications and as a result of this they are present in most of calender scraps.

3. Rubberized Kevlar friction

Since para aramid fibers/Kevlar excels in required reinforcing fiber properties versus steel, they are particularly used in radial tires [7, 19]. Therefore, rubberized Kevlar friction can also be found among fabric scraps. Sometimes, Kevlar fibers can be seen once after the whole bulky material is cut into pieces (Figure 2.0). No Kevlar fibers can be found on its outer layers.

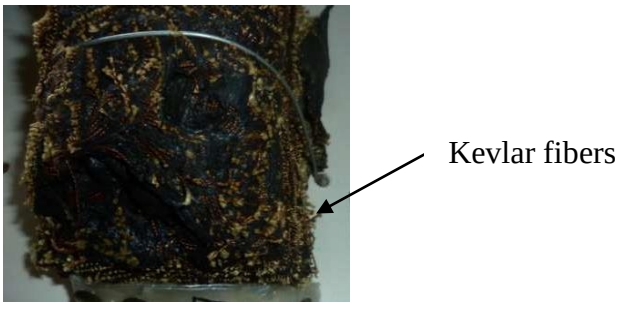


Figure 2.0 Rubberized Kevlar friction

4. Rubberized steel friction.

Brass-plated steel cords were introduced in North America in 1955 and are still dominant in making radial tire belts. Belts with defects are rejected at calender lines and as a result, calender scraps containing steel cords are also present among fabric scraps (Figure 2.1). Even though raw materials are in bulk form, final

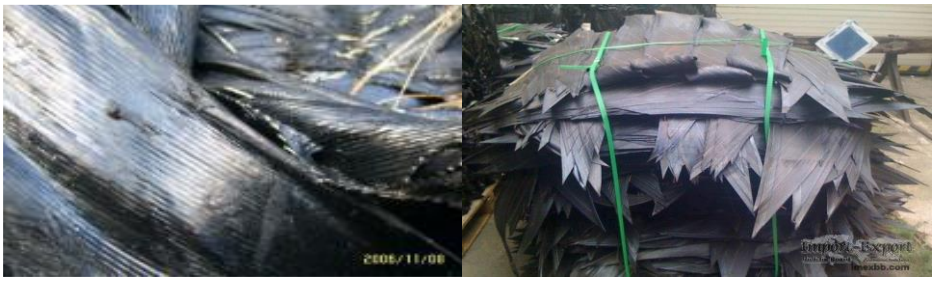


Figure 2.1 Rubberized steel friction

product from the granulator appears in granular form (Figure 2.1) and it is known as Friction cords or Fiber Reinforced Compound (FRC). Long fibers in fabric scraps are chopped into granules during manufacturing of FRC and hence long fibers become short in the product. As the name, Fiber Reinforced Compound implies, the reinforcement/strength is due to the randomly oriented short fibers in rubber compound. Since the product consists of two main constituents e.g. short fibers (reinforcing phase) and rubber compound (matrix phase) which are not soluble in each other [20] and remain recognizable in the applied material, some characteristics of FRC can expect to be resemble to that of a short fiber-polymer composite [21]. In the case of short fiber-polymer composites, short fibers act as viable alternatives to particulate fillers in the reinforcement arena [21]. Likewise, FRC consisting of short fibers already embedded in rubber matrix, can be applied in rubber products as a non-reinforcing filler/diluent, mainly because of its compatibility with virgin rubbers like NR, SBR and other ingredients present in the compound and hardness properties.

Final properties of short fiber-polymer composites depend on several factors such as fiber aspect ratio (average length to diameter ratio), fiber orientation, fiber-rubber interface strength, state of dispersion, nature of matrix and the nature of fiber [21]. Easy processability and greater flexibility in product design associated in short fiber reinforced rubbers is more advantageous in comparison to that of continuous cord reinforcement [21, 22]. In continuous cord reinforcement, fiber ends have very little influence whereas in short fiber rubber composites, they play a significant role in determining the ultimate properties [21]. Short fibers mean that fibers should not be too long to avoid getting entangled with each other during processing, whereas fibers with very small length are not also favorable because stress transfer between the matrix and fibers may not sufficient to achieve required reinforcement [21]. However it was found that aspect ratio (length to diameter ratio) is the main factor (but not the fiber length) which controls the fiber dispersion, fiber-matrix adhesion and optimum performance properties of short fiber-polymer composites [21].

The preferential orientation of fibers in the matrix is the key to the development of anisotropy in the matrix and application of the composites in various industrial products such as V-belts [21]. However, there is no any fiber orientation can be seen with FRC. Instead, randomly dispersed fibers in the rubber matrix can be found. A high degree of fiber orientation could be achieved by repetitive folding and passing through a two roll mill [21]. Moreover, it has been found that fiber orientation depends on mill parameters such as number of passes, nip gap, mill roll speed and nearly 60-70 % fibers get oriented in the direction of applied stress [21]. Two passes of the short nylon 6 and PET fiber reinforced NR composites through the tight nip of a mixing mill is sufficient to orient most of the fibers in the mill direction [21]. Effects of fiber orientation and anisotropy on tensile properties of two short glass fiber reinforced thermoplastics were studied and it was concluded that tensile strength and elastic modulus significantly reduced from in-flow direction to perpendicular-to-flow direction at all temperatures and strain rates [5]. It was observed that lower the nip gap, higher is the anisotropy in tensile properties of the

composite (Kevlar fibers in thermoplastic polyurethane matrix), implying greater orientation of fibers [21].

The concentration of fibers in the matrix plays a crucial role in determining the mechanical strength properties of fiber reinforced polymer composites [21]. Kevlar fiber is considered a reinforcing filler in composites due to its high dimensional stability, superior specific strength, modulus, excellent thermal stability, low density and chemical inertness and its addition to composites increase the tensile strength and percentage of elongation of Kevlar fiber (KF) reinforced wood flour/high density polyethylene composites (WF/HDPE) [23]. In addition, a certain amount of adhesion is required for improving composite performance by increased fiber length in short aramid fiber reinforced polypropylene composite [26]. The improvement in Tensile strength and the elongation at break of the KF reinforced WF/HDPE occurs due to the interfacial adhesion resulted from grafting of KF [23].

In order to obtain a high performance composite, good dispersion of fibers in the matrix is essential. The factors that affect fiber dispersion in polymer matrix are fiber-fiber interaction and fiber length. These factors may cause fibers to get agglomerate during mixing. Therefore, it is necessary to do pre-treatment of fibers in order to reduce interaction between fibers and to increase interaction between fiber and rubber. Fiber dispersion can be improved with increased power input and mixing time. Fiber length should be small enough to facilitate good dispersion. Therefore, commercially available fibers such as nylon, rayon, polyester and acrylic flock must be cut into smaller lengths, of approximately 0.4 mm for better dispersion [21].

A calendered sheet is constructed from a large number of dissimilar materials and all of them (individual rubbers, blends of rubbers, reinforcing materials, process aids and etc.) contribute individually and collectively to the final properties of FRC. Therefore, the knowledge on properties of individual components

of both reinforcing phase and the matrix phase is very important in determining the final properties of FRC.

3.4. a. Properties of individual components in reinforcing phase.

Reinforcing phase of FRC is constituted by randomly oriented discontinuous fibers/textiles or steel fibers, which come from tire cords, used usually to provide the reinforcing strength or tensile component in tires [16]. The carcass, major part of a pneumatic tire is mainly constructed from textile cords and steel cords [3]. Textile materials including rayon, nylon, polyester and aramid currently make up the major tire textile usage [3, 7]. In addition, fiber glass and steel cords [3, 7] are also used. Tire cords are made up from yarns which in turn come from filaments [2]. In other words, filaments are twisted "Z" into yarns and the yarns are back-twisted "S" to form a cord [7, 19]. The size of tire filament, yarn or cord is measured by its linear density/denier (weight in grams of 9000 m) or decitex (weight in grams of 10,000 m) [7]. In calendering process, a good adhesion between rubber compound and fabric cords and steel cords is a critical factor which determines the final quality of calendered sheet and hence fiber/textile cords such as rayon, nylon, polyester and fiberglass are compulsorily treated with an adhesive such as water soluble resorcinol formaldehyde resin (RFL) and brass or copper plated steel cords are usually used to promote cord-rubber adhesion [7]. Therefore, all these ingredients are present in the reinforcing phase of FRC. However, there is neither a fiber orientation in raw materials and nor in final product as in the case of perfect calendered sheets. Moreover, the properties of each and every fiber used in various types of tires are described in the below.

Rayon:

Rayon is considered to be the first of the successful artificial fibers, based on naturally occurring cellulose and it is chemically very similar to cotton which is a natural fiber, widely grown around the world [24].Despite this, rayon in the form of continuous filament is much stronger than cotton [24]. The low

shrinkage, high modulus and good adhesion properties of rayon make it an excellent choice for use in both carcass and belt of passenger radial tires and also in racing tires [7].But it has lost the demand due to higher cost and environmental effects caused during its production [7]. Even though rayon was used in truck tires in the past, it has been displaced by nylon with higher strength and impact resistance [7]. In addition to the advantages mentioned above, there are some disadvantages associated with rayon. For an instance, due to its sensitivity to moisture, fibers may loss a significant proportion of dry strength in moisture conditions [24]. However, this will not pose a significant problem in applications like tires where textile is not directly exposed to absorb moisture [24].

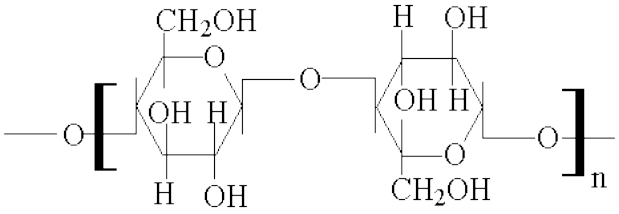
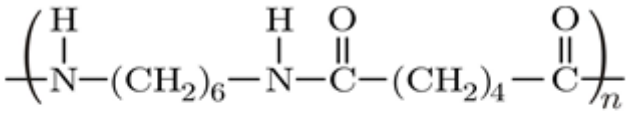


Figure 2.2 Chemical Structure of Rayon

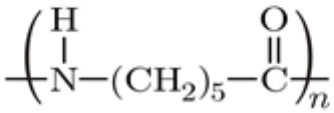
Nylon:

Nylons are aliphatic polyamides [7]. Nylons are one of the most successful synthetic polymers due to its excellent properties such as resistance to chemical attacks, excellent toughness and strength and high abrasion resistance [25]. Therefore nylons are used in many fields, especially as fibers and engineering plastics [25] and applications for these fibers largely fall into two classes; woven nylons are used in clothing textiles, carpets, parachute silk and sails and applications like tire reinforcement cords, ropes, fishing lines and sports rackets require nonwoven nylons [18]. There are various types of nylons, but nylon 6(polyamide-6, polycaprolactam) and nylon 66 (polyamide-66, product of adipic acid / hexamethyl-enediamine condensation) are the two types of nylons frequently used in tires cords [7, 18]. Both materials are less expensive, but more sensitive to moisture and subject to loss in tensile strength if moisture is present at tire curing temperatures [7].Nylon is used in tires of medium or heavy-duty trucks, off-road equipment and aircrafts

which require carcass toughness, impact resistance, high strength and low heat generation [7]. Usually, nylon is used in bias-ply tire carcasses and radial ply carcasses with steel or aramid belts in these applications [7]. Due to its low modulus and low glass transition temperature, nylon is not preferred in using for passenger tires where aesthetics, ride and handling are important [7].



Nylon 66



Nylon 6

Figure 2.3 Chemical Structures of Nylons

Polyester:

Polyester is the condensation polymerization product of ethylene glycol and terephthalic acid [7] and polyester is the general name given to fibers from polyethylene terephthalate [24]. Mostly, polyester combines the strength and elongation characteristics with nylons and modulus characteristics of rayons [24]. This combination of properties make polyester suitable for various applications. For an example, polyester is used in passenger and small light truck tires [7]. In contrast, some problems may be encountered when polyester is applied in certain products, because of its chemically inertness and poor adhesive properties compared with that of nylon and rayon [24]. But an adequate level of adhesion can be obtained by treating polyester with RFL as used with nylon and rayon [7]. Polyester is not suitable for use in high load or high speed or high temperature applications such as aircraft and racing tires, because of rapid loss in properties at tire temperature above about 120 ^{0}C [7].

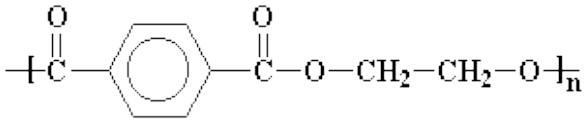


Figure 2.4 Chemical Structure of Polyester

Aramid:

Aramid is a generic term used to describe fibers from wholly aromatic polyamides [19]. Several types of aramid fibers are available. Examples include meta-oriented aramids or poly(m-phenyleneisophthalimide), para-aramids or poly(p-phenyleneterephthamide) and copolyterephthalamides [19]. Among these, para aramids / Kevlar [7] are the most common commercially used type of aramid fibers in reinforced rubber, because of its very high strength and modulus properties [19]. For an example, para aramid fibers are used in reinforcement of radial tires, both in the belt, where modulus contributes to tire performance and in the carcass where strength contributes to tire durability [19]. In para aramids, carbon-nitrogen bond of the amide group has a considerable double bond character which severely restricts rotation about that bond and this partial double bond leads to a resonance-conjugated system. As a result of this para aramid fibers are in yellow colour (Figure 2.0). However, due to the relatively high cost, ithas slowed adoption as a general radial belt material where steel cords are becoming popular [7]. Aramid cords can be used as multiple plies in flat belts as with steel cords [7]. Despite this, aramids should be used as a single ply in carcass applications [7], because, in a multiply carcass construction, poor dynamic fatigue resistance in compression and low elongation of aramids prevent the outer ply from adjusting to average curvature, hence placing the inner plies into compression [7, 19]. This leads to reduce the contribution of inner plies to the total strength [7, 19]. Even though nylon 66 and aramid fiber are very similar in chemical functionality, para aramid fibers are much more difficult to bond to rubber due to high crystallinity of para aramids, which create difficulty in gaining chemical access to the amide groups and decreased reactivity caused by the strength of inter-crystalline hydrogen bonds [19]. Therefore, para aramid fibers are treated firstly with epoxy resin followed by a second coating of an RFL emulsion [19] to get required adhesion properties.

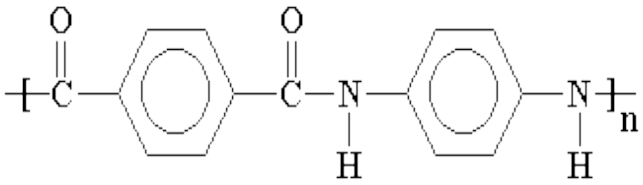


Figure 2.5 Chemical Structure of p-Aramid fiber

Fiberglass:

In 1960, fiberglass was introduced to the US tire industry with the development of the belted-bias tire [7]. But this tire was soon replaced by the radial tire [7]. Later fiberglass was quickly replaced by steel as the premier belt material [7]. However glass fibers still have excellent properties to apply as a belt material; its specific strength and stiffness are equal to that of steel, whereas specific gravity is only about 2.54 compared to 7.85 for steel and modulus is 2150 cN/tex compared to 1500 cN/tex for steel [7]. Furthermore it shows good adhesion properties with rubber compound and in this case each filament of fiberglass is treated with RFL adhesive before filaments are twisted into yarns [7].

Steel:

Nowadays steel cord predominates in the belt mainly due to its high specific strength and stiffness. Modulus is about 1500 cN/Tex which is quite higher in comparison to that of rayon, nylon and polyester [7]. In addition properties like less moisture regain and high specific gravity make the steel as best choice for belt material [7]. Therefore it is estimated that steel belts comprise 10-12 % of the tire weight in radial passenger and light tires whereas the fabric cord content in carcass is about 5 % of the total tire weight [7].

3.4. b. Properties of individual components in matrix phase.

Matrix phase of FRC is constituted by the rubber compound which is used to produce body plies and belts of pneumatic tires. Rubber matrix is the co-polymer, styrene-butadiene (SBR) or a blend of natural rubber (NR) and SBR [16]. Natural rubber (NR) which chemically refers to as cis-1,4-polyisoprene is obtained from *Hevea brasiliensis* tree [17,26].NR is used in manufacturing of a large variety of tires including large truck tires, off-the-road giant tires, aircraft tires, because of its excellent properties such as high abrasion or wear resistance, electrical resistance, chemical resistance to acids, alkalies and alcohols, toughness, good resilience, pure gum vulcanizate strength and high tackiness [26]. Styrene-butadiene rubber (SBR) is a copolymer made of styrene and butadiene [26] and is the one of most commonly used types of rubbers in manufacturing tires. Even though most of the properties of SBR is quite compatible with NR, some properties of SBR like pure gum tensile strength, tackiness, heat buildup are inferior to NR [17]. SBR is less chemically active than NR and hence is slower curing, requiring more accelerators than with NR [17]. In contrast, excellent resistance to abrasion and resistance to degradation under heat of SBR, make it the most suitable material for automobile tires [17, 26]. In compounding, blending of NR and SBR is preferred in order to improve the physical and mechanical properties of rubbers and to obtain good processing characteristics of rubber compound [26].

In addition to the major components, rubber matrix may contain reinforcing fillers such as carbon black, used to improve tensile strength, tear strength and abrasion resistance, processing aids such as petroleum oils, used to control viscosity, reduce internal friction during processing and improve low temperature flexibility in the vulcanized product, vulcanizing agents such as organo sulfur compounds, used to catalyse the vulcanization process, activators such as zinc oxide and stearic acids, used to activate the curing process and to preserve the cured properties [3, 16], accelerators, used to increase the rate of vulcanization, anti-oxidants and anti-degradants, used to retard the degradation caused by oxidation,

heat and light, retarders, used to avoid the danger of scorching/pre-vulcanization and peptizers, used to promote the mastication process [3].

FRC manufactured from calendering scraps can be considered a rich material, because of its composition and properties as described above. Its composition and properties are very complex and vary significantly depending on the application. However, techniques like Differential Scanning Chromatography (DSC), Thermal Gravimetric Analysis (TGA), Fourier Transform Infrared Spectroscopy (FTIR), Gas Chromatography-Mass Spectrometry (GC-MS) and High Performance Liquid Chromatography (HPLC) can be suggested to examine the components in FRC. Due to its complexity, component identification and compositional analysis of FRC has become rather a very difficult and a costly process.

3.5 Application of Fiber Fillers in Rubber Compounds

Carbon black and silica are the most frequently used fillers in rubber industries because reinforcing ability of them are relatively high. Usually, fillers are used in order to lower the cost of compound and also to improve the mechanical and dynamic properties of the polymer material [5,28]. Fiber filled polymers or short fiber reinforced polymer composites are becoming more and more popular as alternative low cost materials in various application fields like automotive industry, building and construction industry, packaging, furniture and consumer goods [28, 29]. They combine the advantages of polymers like good impact resistance and low weight with the high stiffness and strength of reinforcing fibers [26]. Furthermore, they are suitable for mass production as conventional techniques like extrusion and injection molding [5, 29].

In recent years, uses of plant based natural fibers for the production of bio sustainable composites is increasing in research areas and manufacturing because of their ease of processing, low cost, low density, biodegradability and good

mechanical properties. Further, natural fibers can be added to rubber to improve or modify certain properties such as green strength, creep resistance, hardness, aging resistance, dynamic mechanical properties, dimensional stability during fabrication, and real-time service [28].

In applications like automobile tires, combined use of short fibers and silica have been applied to improve the rolling resistance, abrasion resistance and dimensional stability of tire treads. It is a must to decrease the rolling resistance of car tires in order to achieve a low fuel cost. Even though the rolling resistance can be decreased by incorporating carbon black, it deteriorates the abrasion resistance of tire tread. Therefore, in order to decrease rolling resistance without deteriorating abrasion resistance, silica and silane coupling agent as reinforcing materials other than carbon black are used. However, this composition consisting silica and silane coupling agent is still facing a problem that shrinkage of the extrudate of composition is large. But short fibers in the composition tends to orient in the direction of extrusion thereby inhibiting the shrinkage of the rubber sheet. Further it has found that there is no limitation on materials constituting short fibers as long as they are having dimensions like diameter (D) of 0.1 μm–0.5 μm, the length (L) of 50 μm-500 μm and L/D ratio of 100-5000. Therefore, various types of fibers including synthetic fibers like nylon, aramid, polyester, semisynthetic fibers like rayon and natural fibers like cotton can be used for this type of tread applications [30]. Furthermore, it is necessity to enhance tire tread traction on icy roads in some countries where there are harsh, long winters. In order to improve this tread traction property, organic fibers like cellulose having hydroxyl groups on the surface have been used with silica as a reinforcing material in treads of winter tires [31]. Styrene-butadiene is the most commonly used rubber matrix in tires [16]. When short fibers are added, they act as modifier for this rubber matrix as its addition affects the vulcanization process and on formation of crosslinks and further it slightly increases tensile strength but decreases the elongation at break of the matrix [28].

In solid tire applications, it has been found that highly oriented fibers in the circumferential direction in the base rubber reduce the dimensional instability caused by sudden stop-and-go operations such as in forklifts of the tire, hence its slippage on the rim. However, with the addition of short fibers to the base rubber, its heat build-up potential get increased significantly. At higher temperatures, adhesive bond between the rim and the base rubber is severely compromised and leads to exactly the same failure, slippage that the fiber reinforcement was supposed to remedy [21].

It has been found that low crack propagation in the elastomer occurs when partially oriented yarns (POY) are processed into short fibers and used as a fiber reinforcement in an elastomer. Therefore, short fiber reinforced components can replace conventional components in a tire such as the overlay ply in the crown area of tires that are subjected to high speeds.POY fibers consist of polymer chains having large disordered domains. When the fiber is subjected to elongational strain, the disordered domains can stretch in much the same way that an elastomer chain expands when subjected to a force, and therefore the fiber has a low tensile modulus and tensile strength but a high ultimate elongation. The POY fibers add almost as much to the stiffness of an elastomer as do fully oriented flexible chain fibers when incorporated into a composite, while absorbing energy as they stretch which would otherwise be available to the elastomer to contribute to fracture propagation.POY short fibers, preferably POY nylon 66 or nylon 6, will provide a moderate increase of low strain modulus and a readily available mechanism of energy dissipation upon deformation due to an increased orientation in the molecular structure of the partially oriented fiber (strain induced crystallization). Typically, an elastomer matrix containing POY fibers have nearly equal stiffness and lower cut growth rate, higher hysteresis, and similar hardness, tear strength, tensile strength and ultimate elongation properties as compared to an elastomer matrix which is reinforced with fully oriented flexible chain short fibers. Thus it is possible to achieve nearly the same increase in stiffness using POY fibers, in a composite, other properties being

equal, as it is using standard fibers, while obtaining significant advantages in cut growth resistance [32].

When tread rubber composition comprises of polyethylene fiber as the short fiber and a blowing agent in combination, the braking ability of the tire on ice is remarkably improved. When the rubber composition comprising polyethylene short fiber is used for a tread rubber, gases in the rubber are gathered at the polyethylene resin having a decreased viscosity during vulcanization and long closed cells having a protective layer of the resin around the cells are formed. Therefore, the vulcanized rubber contains approximately spherical closed cells and the long closed cells. The long closed cells are covered with the layer of polyethylene and are not so easily deformed by input forces from the road surface as the spherical ones are deformed. As a tire is driven on ice, a layer of water is formed between the tire and the surface of ice by the pressure of the tire to the surface and by the heat of friction, and when the tire is prepared by using the above rubber composition comprising polyethylene short fiber for the tread rubber, the generated water within the area of the tire contacting the surface of ice is removed through numerous depressions formed from the spherical closed cells and the long closed cells coming out to the surface with the abrasion. Water is removed through the depressions formed from the long closed cells more efficiently than through the depressions formed form the spherical closed cells. Therefore, water is removed more efficiently in the present tire than in tires having spherical closed cells alone. It is preferable that the short fiber is oriented in the rubber composition in a manner such that the longitudinal direction of each short fiber is placed in the circumferential direction of the tire. Long depressions arranged in the same direction play the role of gutters and efficiently remove water in the area of the tire contacting the surface of ice. Therefore, the friction coefficient on ice can be increased and the excellent braking ability on ice can be exhibited [33].

When the present environment issues such as global warming are concerned, it is a must to decrease the rolling resistance of pneumatic tires.

Therefore low rolling resistance of tires are obtained by using tread rubber compounds reinforced with silica instead of carbon black. Even though these compounds have a very low hysteresis loss, their electrical resistance is very high. If the tread portion of a tire is made of such an insulation, when the vehicle body is electrostatically charged, problems such as car fire, radio noise, disturbing of light electrical appliances may arise. It is better to decrease the volume of the conductive rubber for decreasing the hysteresis loss. In this case, however, the carbon black content is inevitably increased to obtain a necessary conductivity. As a result, in regard to the properties like hardness, wear resistance, it is liable to become difficult to keep a proper balance between the conductive rubber and low hysteresis loss rubber. Further, the increased hysteresis loss of the conducive rubber by the addition of carbon black is liable to void the improved rolling resistance. In order to solve this problem, rolling resistance and conductivity are improved by decreasing the carbon black content of the tread rubber and adding conductive reinforcing short fibers instead. For the reinforcing short fibers, synthetic organic fibers such as nylon, rayon, vinylon, polyethylene, polystyrene, polyvinyl chloride, polyvinylidene chloride, aromatic polyamide, polyethylene terephthalate, polypropylene, cellulose and plant fibers made of cellulose and the like such as pulp and inorganic fibers such as glass, alumina can be used. To maintain plasticity of the finished rubber, organic fibers such as nylon fibers and pulp are preferably used. Especially nylon fibers are preferable for the superior extensibility, flexibility and strength. In this case conductive short fibers can be formed by coating reinforcing short fibers with a conductive substance [34].

Furthermore, it has been found that vulcanized aramid reinforced elastomers are especially suitable in pneumatic tires, and most particularly as carcass plies and reinforcing belts between the tread and carcass in radial tires. The fibers are composed of a trunk portion having a length of about 0.2-5 mm, a diameter of about 0.005-0.02 mm (5-20 micrometers), and an aspect ratio greater than 100, and numerous fibrils extending outwardly from the trunk and having diameters substantially smaller than the trunk diameter. The surface area of the fibers is from

about 4 to about 20 square meters per gram. The rubber may be compounded with the aramid fibers (preferably premixed with carbon black) and other compounding ingredients according to conventional methods using conventional processing equipment, for aramid fiber loading up to about 10 phr. Mixing equipment may include one or more Banbury mixers. Usually more than one mixing stage is desirable. Then the compounded rubber may be calendared or otherwise shaped or extruded under shear conditions. A preferred shaping apparatus is a four-roll calendar although two or three roll calendars and other types of shear producing shaping apparatus, as for example an extruder may be used. Calendar rolls are generally preferred when a sheet is desired, and an extruder is generally preferred when a shaped component is desired. It is an important feature that the aramid fibers get oriented in the calendared or extruded mixture and in the vulcanizate which is formed on curing. The aramid fibers are oriented in substantially parallel, unidirectional configuration in the lengthwise direction of a calendared sheet, or in the direction of extrusion in an extruded part. Incorporation of the fibers results in substantial increase in stiffness and modulus [35].

In literature, it has mentioned that a polymer composition containing micro fibers and macro fibers demonstrates the advantages of the micro and macro fibers while minimizing the disadvantages of both. For an example, base polymers such as styrene butadiene rubber (SBR), polybutadiene rubber, nitrile butadiene rubber (NBR), polychloroprene rubber, natural rubber, EPDM (ethylene propylene diene monomer rubbers), macro short fibers like polyamides, polyesters, polyolefins, cellulosic fibers, polyimides, polyurea, polyurethane and polybenzimidazole and micro reinforcing polymers like polyamides, polyesters, polyolefins, polyurethanes can be used in forming polymer blends. Such fiber loaded polymer blends may be used in the tread base to reduce cut growth, and reduce hysteresis, improve resistance to penetration by foreign objects, and improve stiffness and handling; in the tread to reduce chipping and chunking and improve rolling resistance; the belt package to increase stiffness and improve cut growth and cracking properties; the apex to stiffen the apex and reduce hysteresis; the sidewall to increase toughness

against bruises and cutting; and the bead area to improve stiffness and improve cut growth properties. Further, it is believed that an elastomeric composition employing macro fibers and micro reinforcing polymer can be used to reduce the need for an overlay in a tire since such a composition can be used to increase the stiffness of the belt package. It is believed that the gauge of the belt package can be reduced and the fabric in the overlay can be reduced, and possibly the overlay can be eliminated [36].

4. EXPERIMENTAL

4.1 Materials

Rubberized nylon frictions needed to characterize and standardize friction cords were received in bulk form from US Lanka Rubber Solutions Private Limited, Seeduwa. Eight chunky materials were randomly selected from its huge storage of calender scraps and were labelled them as R_1, R_2, R_3, R_4, R_5, R_6, R_7 and R_8 respectively. Each material was weighed and recorded. Metal wires were present in R_1. Further, it could be observed that R_2, R_5 and R_6 contained some pieces of polyethylene and R_3, R_4 and R_7 contained cardboards.

Natural rubber of RSS – grade III was purchased locally to prepare the series of filled rubber compounds. Compounding ingredients including zinc oxide (ZnO), stearic acid, carbon black (N330), N-cyclohexyl-2-benzothiazolesulfenamide (CBS), pre-vulcanization inhibitor (PVI), sulfur and wood resin were imported. Nylon flocks were purchased locally, chopped friction cord in 8 mm were supplied by US Lanka Rubber Solutions Private Limited in Seeduwa. N-cyclohexyl-2-benzothiazolesulfenamide (CBS) was used as an accelerator. It is derived from 2-mercaptobenzothiazole and amine is oxidatively bound to the mercapto sulphur. ZnO and stearic acid ($C_{18}H_{36}O_2$) were used as activators. High structure black (N330) was used as a filler. Pre-vulcanization inhibitor (PVI) was used as a retarder. It belongs to the type of N-cyclohexyl-thiophthalimide. Wood rosin was used as a tackifying resin and it is based on natural feedstock, gained from pine trees.

4.2 Preparation of Materials for Characterization of Friction Cords

Firstly, material, R_1 was cut using a XQL-16 type rubber cutter into large pieces. Weights of these large pieces varied between 1-5 kg. Portion of R_1 which contained metal wires was rejected at the rubber cutter. Then, remaining large

pieces were further cut into small pieces of weights 250 g-350 g using a guillotine rubber cutter. Granulator screen carrying holes with the diameter of 25 mm was fitted to obtain granules of cord length of 25 mm. Then those small pieces of R_1sample were fed into the rubber granulator via a conveyor in order to obtain friction cords in granular form. Since those small pieces were fed in to the granulator through a metal detector, pieces containing further metal pieces could be rejected at this stage. 50 kg of friction cords could be obtained at the granulator within 5 min. The processing of material, R_1 in to friction cords of cord length 25 mm is depicted in Figure 2.6.At this stage temperature of the output was measured using an infrared thermometer. Granulator had a temperature control system attached to it and thus that system automatically controlled the temperature below 70 ^{0}C. Then the processed quantity (50 kg) of R_1sample was kept lying on the floor in cooling area. When its temperature reaches below 40 ^{0}C six samples, 200 g each were randomly collected and labelled as S_1, S_2, S_3, S_4, S_5 and S_6respectively. Likewise, materialsR_2, R_3, R_4, R_5, R_6, R_7 and R_8were processed and six granulated samples (S_1-S_6) from each material were collected. Finally 48 samples were collected and all of them were 25 mm in cord length. Pieces of polyethylene present on R_2, R_5 and R_6 and cardboards present on R_3, R_4 and R_7 were removed manually before cutting them in to pieces and during cutting both at the rubber cutter and at the guillotine. The granulator screen was removed, cleaned and refitted to the grinder at every time when the collection of relevant six granular samples (S_1-S_6) of one material was finished. The purpose of cleaning granulator screen was to avoid mixing granules of one material with that of other material in the cutting area of the granulator and hence to obtain pure samples, because there is a possibility to get trapped some granules of previously processed material.

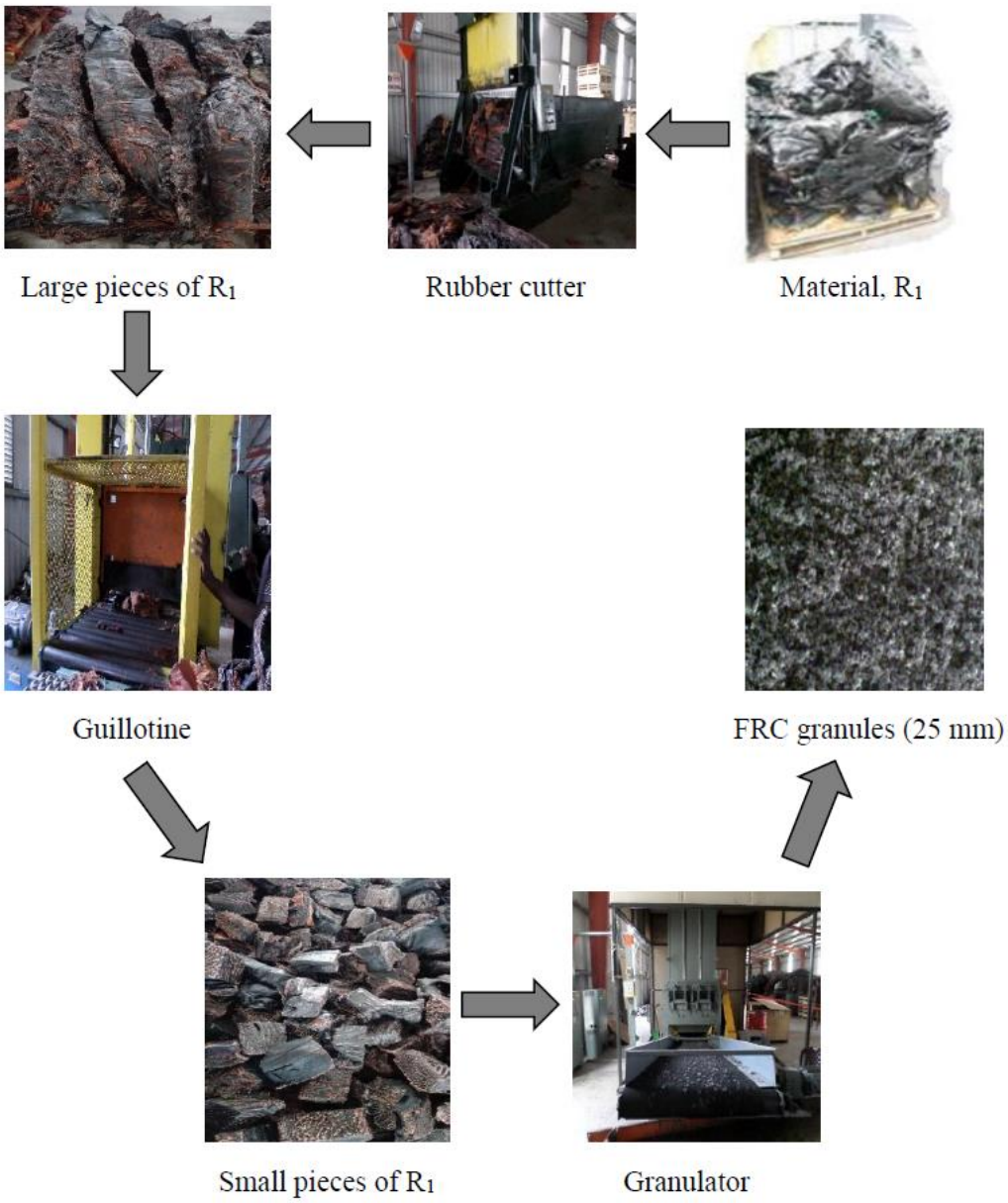


Figure 2.6 Processing of material, R_1

4.3 Preparation of Blends for Standardization of Friction Cords

In the section 4.2, the procedure by which friction cord samples, 50 kg each with cord length of 25 mm processed and collected from R_1, R_2, R_3, R_4, R_5, R_6, R_7 and R_8 was described. Further, it has mentioned that six samples, each weight of 200 g was randomly collected from each 50 kg quantity of friction cord sample in

order to be tested for characterization of friction cords. Once the characterization of friction cords was completed, remained quantities of R_1-R_8 samples were used in preparation of samples for standardization of friction cords. Therefore, samples were taken in granular form to mix them in different weight proportions to prepare blends in order for standardization of friction cords.

In standardization, samples of R_2, R_3 and R_5 were mixed in different weight proportions to prepare five blends including blend No: 1, blend No: 2, blend No: 3, blend No: 4 and blend No: 5. Weight of R_2 sample used in blends were gradually increased and hence 100 g, 200 g, 300 g, 400 g and 500 g of R_2were used in preparing the blends (No: 1-No: 5). Table 1.0 shows the figures for blend No, sample No, weight of each sample used in preparing the blend, weight ratio used in blend and total weight of the blend.

Table 1.0
Preparation of blends (No: 1-No: 5)

Blend No	Sample No	Weight of sample/g	Weight ratio	Total weight of the blend/g
1	R_2	100	1	
	R_3	100	1	
	R_5	100	1	300
2	R_2	200	2	
	R_3	100	1	
	R_5	100	1	400
3	R_2	300	3	
	R_3	100	1	
	R_5	100	1	500
4	R_2	400	4	
	R_3	100	1	
	R_5	100	1	600
5	R_2	500	5	
	R_3	100	1	
	R_5	100	1	700

Above five blends (No: 1-No: 5) were prepared with varying weights of R_2 sample only. Then blend No: 6-blend No: 9 were prepared with the increased weight of R_5 sample. Therefore, 200 g, 300 g, 400 g and 500 g of R_5 sample were mixed with R_2 sample and R_3 sample by keeping the weights of both R_2 and R_3 constant at 100 g. Table 1.1 illustrates the blend No, sample No, weight of each sample used in preparing the blend, weight ratio used in the blend and total weight of the blend.

Table 1.1
Preparation of blends (No: 6-No: 9)

Blend No	Sample No	Weight of sample/g	Ratio of blending	Total weight of blend/g
6	R_2	100	1	
	R_3	100	1	
	R_5	200	2	300
7	R_2	100	1	
	R_3	100	1	
	R_5	300	3	500
8	R_2	100	1	
	R_3	100	1	
	R_5	400	4	600
9	R_2	100	1	
	R_3	100	1	
	R_5	500	5	700

Above blends (No: 1-No: 9) were prepared using the samples from same materials including R_2, R_3 and R_5 only. In preparing the blend No: 10, sample from R_8 was substituted for R_5. Table 1.2 shows data for blend No, sample No, weight of each sample used in preparing the blend, weight ratio used in the blend and total weight of the blend.

Table 1.2
Preparation of blend No: 10

Blend No	Sample No	Weight of sample/g	Ratio of blending	Total weight of blend/g
10	R_2	100	1	300
	R_3	100	1	
	R_8	100	1	

In addition, blend No: 11 was prepared by mixing 100 g of R_1, 100 g of R_4 and 100 g of R_7 in the weight ratio of 1:1:1. In next three blends, weight of one component such as weight of R_1 in blend No: 12, weight of R_4 in blend No: 13 and weight of R_7 in blend No: 14 were doubled keeping the weight of remaining two samples at 100 g. Figures for blend No, sample No, weight of each sample used in preparing the blend, weight ratio used in blend and total weight of the blend relevant to blends (No:11-No:14) are shown in Table 1.3.

Table 1.3
Preparation of blends (No: 11-No: 14)

Blend No	Sample No	Weight of sample/g	Ratio of blending	Total weight of blend/g
11	R_1	100	1	300
	R_4	100	1	
	R_7	100	1	
12	R_1	200	2	400
	R_4	100	1	
	R_7	100	1	
13	R_1	100	1	400
	R_4	200	2	
	R_7	100	1	
14	R_1	100	1	400
	R_4	100	1	
	R_7	200	2	

4.4 Preparation of Rubber Compounds.

The series of filled rubber compounds were prepared. Formulations of rubber compound were given in Table 1.4. They differed by fiber filler composition in where nylon flocks were partially and completely replaced with

friction cord. Compounds were formulated such a way that the total fiber filler amount was 100p.p.h.r. All compounds were prepared in two stages. First Master batch was prepared in an internal mixer of laboratory type with intermeshing rotors as per mixing cycle in Table 1.5.

Table 1.4
Formulations of rubber compounds

Compound No	1	2	3	4	5	6
Additives	p.p.h.r	p.p.h.r	p.p.h.r	p.p.h.r	p.p.h.r	p.p.h.r
Rubber	100	100	100	100	100	100
ZnO 99.5	5.0	5.0	5.0	5.0	5.0	5.0
Stearic Acid	1.4	1.4	1.4	1.4	1.4	1.4
N330	45	45	45	45	45	45
Nylon flocks	100	80	60	40	20	0
Friction cord	0	20	40	60	80	100
Wood resin	1	1	1	1	1	1
CBS	1.5	1.5	1.5	1.5	1.5	1.5
Sulfur	2.0	2.0	2.0	2.0	2.0	2.0
PVI	0.3	0.3	0.3	0.3	0.3	0.3

Table 1.5
First stage mixing cycle for compounding in internal mixture

Cycle time / min	Procedure
0	add rubber
2	add stearic acid, ZnO, filler, antioxidant
5	dump

Curing system together with PVI was added in an open two roll mill of laboratory size as per mixing cycle given in Table 1.6. The cure characteristics of rubber were compounds were determined with α- technology MDR2000 rheometer. Torque versus time dependences were taken at temperature of 180 ^{o}C. Minimum torque, maximum torque, scorch time t_{10} and cure time t_{90}

were recorded. Obtained results were used for estimation of time required for vulcanization of test samples.

Table 1.6
Second stage mixing cycle for compounding in two roll mill

Cycle time / min	Procedure
0	add master batch
4	add MBTS, Sulphur , PVI
15	Sheet out

4.5 Testing

4.5.1 Testing for characterization of friction cords

a) Fiber content

Randomly selected eight materials (R_1-R_8) for carrying out this experiment contained rejected calender plies. Before processing these materials in to friction cords, a small test piece in the size of 2″ × 2″ (Figure 2.7) was cut and separated from each chunky material. Therefore, totally eight test pieces were taken separately from eight materials and each test piece was weighed and then fibers of

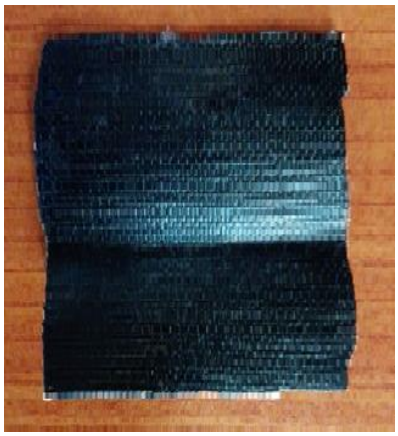


Figure 2.7 Initial test piece

each test piece were pulled out by hand (physical separation). Then the fiber portion (Figure 2.8) was weighed. Finally, percentage of fiber by weight was calculated using the equation (1) and recorded as the fiber content (wt. %) in Table 1.0.

Figure 2.8 Separated fiber and rubber portions

$$\text{Fiber content (wt.\%)} = \frac{\text{Weight of fiber portion}}{\text{Weight of the test piece}} \times 100 \quad (1)$$

In the section 4.2, it has described the procedure by which six granulated samples, 200 g each was collected from all eight chunky materials (R_1-R_8). Then each sample was milled out on a laboratory rubber mill and a sheet (5 mm in thickness) was obtained. Finally, 48 sheets were obtained for all eight materials and each and every sheet was tested for specific gravity (SG), hardness (HD), tensile strength (TS), elongation at break (EAB), moisture content, rheological properties.

b) Specific gravity

A sample from each sheet was cut and put on to a mould and then mould carrying samples were inserted into a rubber hydraulic press for curing. Since the mould contained six cavities, six samples could be cured at a time. All samples were cured at 150 ^{0}C for 15 min under the pressure of 150 bar. Diameter of the test specimens was 28 mm and the thickness was 10 mm (Figure 2.9). The test was carried out at 25 ^{0}C and all test specimens were maintained at 25 ^{0}C for 24 hours before testing. Average weight of all 48 samples was 8 g.

Specific gravity of each and every sample was measured as per ISO 2781:2008 standard. WTB600AU type density meter with precision of 0.001 g equipped with a stationary support for the immersion vessel above the balance pan (pan straddle) was used to measure the specific gravity of each sample. Firstly, all test specimens were visually inspected before measurement so as to confirm that those were free from pores and nicks. Then the test piece was weighed to the nearest milligram in air. Repeated the weighing with the test piece immersed in deionized water at 25 ^{0}C. At this stage, it was made sure that no air bubbles adhered to the test piece. When the balance showed that the reading for mass of the test piece immersed in water was stable, the "enter" button was pressed. Then it automatically calculated the specific gravity of test piece. Even though, the balance gave each reading with the precision of 0.001 g all results were calculated to the nearest 0.01 g and recorded.

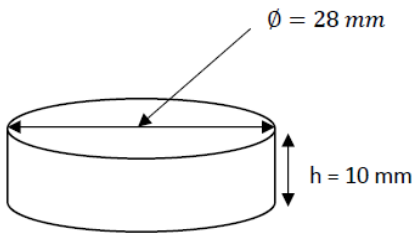


Figure 2.9 Test specimen for measuring specific gravity

c) Hardness

Same test specimens used for measuring specific gravity (Figure 2.9) was used for testing of hardness of all samples. Hardness of all samples were measured as per ASTM D 1415. Further, all test specimens were visually inspected before measurement and those were with smooth surfaces free from dust and cracks. Hardness is commonly defined as the resistance to indentation under specified conditions [3]. Dead load hardness tester was used to measure the hardness which is based on indentation depth. This instrument converts the indentation depth into International Rubber Hardness Degrees (IRHD), the scale of which ranges from 0 (infinitely soft) to 100 (infinitely hard) [3].

d) Tensile strength

A sample from each sheet was cut and put into a tensile mould. Then the mould with sample was inserted in to a rubber hydraulic press for curing. Each sample was cured at 150 ^{0}C for 15 min under the pressure of 150 bar and at the end of curing, a smooth flat sheet could be obtained. Then three dumbbell shaped specimens were punched out using a cutter from one moulded sheet in the milling direction. Before testing, the thickness was measured using a thickness gauge at three points along the center straight portion of each dumbbell piece and the average was 2 mm. Test specimens of all samples were cut as per ASTM D 412 and tested using H10KT tensile testing machine with a load cell of 5kN. Dimensions of the test piece is shown in Figure 3.0. This test was carried out at the temperature of 25 ^{0}C. Each dumbbell test specimen was held symmetrically in the tensile testing machine by means of self-tightening grips to distribute tension uniformly over the cross section. Rate of grip separation was 500 mm/min. The machine itself recorded the displacement between its cross heads on which the specimen was held. Once the machine was started, applied load on the specimen got increased. At the same time QMAT software installed on the computer recorded the load and extension of the specimen and stress-strain curve was obtained at the end. This stress-strain curve described the parameters including tensile strength, yield strength, elastic modulus, maximum force, stress at break, force at break and percent elongation (elongation at

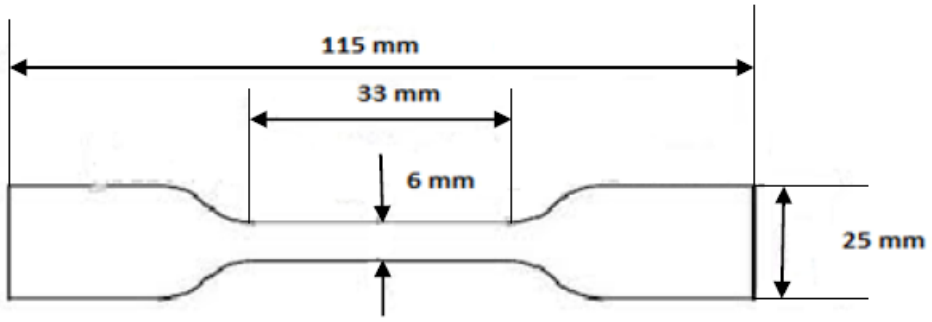


Figure 3.0 Dimensions of dumbbell test piece

break). But only the results of tensile strength and elongation at break were recorded in this experiment. Three dumbbell shaped specimens from each sample were tested

and average results were taken as the tensile strength and elongation at break of that sample. Tensile strength is usually defined as the force on unit area of original cross section which is required to break the test specimen, the condition being such that the stress is substantially uniform over the whole of cross section [3]. And the elongation at break is the maximum value of the elongation expressed as a percentage of the original length [3].

e) Moisture content

Moisture analyzer MAC 50 with precision of 0.001 % was used to measure the moisture content of each sample. Before samples were milled, 48 samples, each weight of 5 g in granular form were separated and those were placed and dried at 100 ^{0}C using the moisture analyzer until the constant mass was obtained. At the end, the instrument automatically calculated the loss of weight of each granular sample due to the evaporation of moisture as a percentage. Value obtained with the precision of 0.001 % was calculated to the nearest 0.01 % and was recorded as the moisture content (wt. %) in FRC.

f) Rheological/curing properties

Processing capacity of a material can be predicted using its rheological properties. Maximum torque, minimum torque, scorch time are most frequently used curing properties obtained using a rheometer to study the cure characteristics of a material [2]. Test specimens for all sheeted samples were prepared and tested for curing properties as per ASTM D 2084. Test samples cut from all sheets were circular with the diameter of 30 mm, thickness of 10 mm and the weight of 10 g. Test was carried out at 150 ^{0}C for 20 min, arc 3^0 using an oscillating disk rheometer (ODR). The increase in torque during vulcanisation is considered to be proportional to the number of cross-links formed per unit volume of rubber [17]. The torque was automatically plotted against time to give so-called rheographs. The results for t_{s2} (time for the rise in torque by 2 units), t_{c90} (time for 90 % rise in torque or time for 90 % completion of the crosslinking reaction),

minimum torque (M_L) and maximum torque (M_H) given on rheographs were recorded in Tables 1.1-1.8

4.5.2 Testing for standardization of friction cords

Firstly, six samples from blend No: 1 were randomly collected and labelled them as S_1, S_2, S_3, S_4, S_5 and S_6. They were tested for properties such as specific gravity, hardness, tensile strength, elongation at break and the moisture content. Likewise, samples from blend No: 2, blend No: 3, blend No: 4 and blend No: 5, six samples from each blend were collected and tested to study the variation in properties. Thus totally 30 samples were collected from blends (No: 1-No: 5) and tested.

As in the case of blends (No: 1-No: 5), randomly collected six samples labelled as S_1, S_2, S_3, S_4, S_5 and S_6 from blend No: 6, blend No: 7, blend No: 8 and blend No:9 were tested for specific gravity, hardness, tensile strength, elongation at break and moisture content. Therefore, totally 24 samples were collected from blends (No: 6-No: 9) and tested for physical properties.

Furthermore, six samples were randomly collected from blend No: 10 and were labelled as S_1, S_2, S_3, S_4, S_5 and S_6. Then specific gravity, hardness, tensile strength, elongation at break and moisture content of these six samples were tested.

Six samples collected and labelled as S_1, S_2, S_3, S_4, S_5 and S_6 from each blend including blend No: 11, blend No: 12, blend No: 13 and blend No:14 were tested for specific gravity, hardness, tensile strength, elongation at break and moisture content.

Dimensions of all test pieces relevant to testing of specific gravity, hardness, tensile strength, elongation at break and standard procedure used in measuring were as same as used in testing for characterization of friction cords in sub section 4.5.1.

4.5.3 Testing for effects of friction cords on properties of rubber compound

The test rubber samples were prepared by curing the raw rubber in the compression molds fixed to platens of a laboratory type "MOORE" hydraulic press preheated up to 150 ºC along with plates. After vulcanizing the cured samples were de-molded, cooled and punched out of cured rubber sheet. Punched samples were left for conditioning for at least 3 hours at temperature of 23 ± 2ºC prior to testing. Specific gravity, hardness, tensile strength, elasticity modulus at 100% elongation were determined according to appropriate standards. Dimensions of all test pieces relevant to testing of specific gravity, hardness, tensile properties and standard procedure used in measuring were as same as used in testing for characterization of friction cords in sub section 4.5.1. Elasticity modulus at 100 % elongation is the value of tensile stress required to stretch the test piece from the unstrained condition to 100 % elongation [3] and that parameter was recorded using the stress-strain curve obtained during the tension test.

5. RESULTS AND DISCUSSION

5.1 Characterization of Friction Cords

As it has been mentioned in sections, 4.2 and 4.5.1, 48 granulated samples in cord length of 25 mm were prepared and tested for specific gravity, hardness, tensile strength, elongation at break, moisture content and rheological properties under the characterization of friction cords. In addition, eight test pieces (Figure 2.7) were taken from eight bulky raw materials prior to processing in order to determine the rubber to nylon ratio of friction cords. Therefore, Tables 1.7-3.3show the results for the characterization tests carried out in section, 4.5.1. Further, the average values of all properties for all materials (R_1-R_8) were calculated and recorded in Tables 1.8-3.3

Table 1.7
Fiber content of materials (R_1-R_8)

Rubberized nylon friction No	Fiber content (wt. %)
R_1	33.93
R_2	25.69
R_3	33.42
R_4	29.18
R_5	30.27
R_6	27.12
R_7	24.62
R_8	34.84

5.1.1 Fiber content test result

In comparison with each other, fiber content of R_1, R_3, R_5 and R_8 were higher than that of R_2, R_4, R_6 and R_7 (Table 1.7). Fiber content of R_1, R_2, R_3, R_4, R_5, R_6, R_7 and R_8 varied between about 24.62 % - 34.84 % and thus the remaining rubber content varied between 65.16 % - 75.38 % was the rubber content. Therefore,

it was obvious that rubber portion was the major while fiber portion was the minor in selected eight materials consisting of rejected calender plies.

Table 1.8
Rheological properties of raw material, R_1

Sample No	T_{s2}	T_{c90}	M_L	M_H
	m : s	m : s	lb-in	lb-in
S_1	2:02	8:36	27.06	87.4
S_2	1:56	9:55	23.99	89.13
S_3	1:57	7:44	27.12	105.54
S_4	1:54	7:12	25.82	104.93
S_5	2:17	7:37	21.98	104.85
S_6	2:05	10:13	27.33	87.09
Average	2:01	8:32	25.55	96.49

Table 1.9
Physical properties of raw material, R_1

Sample No	SG	HD	TS	EAB	Moisture content
	g/cm^3	IRHD	MPa	%	wt. %
S_1	1.15	92	9.83	88.45	0.95
S_2	1.14	93	13.46	62.93	0.86
S_3	1.15	92	6.81	127.2	0.88
S_4	1.14	92	13.15	81.63	0.87
S_5	1.15	90	13.29	61.73	0.83
S_6	1.15	88	13.15	62.4	1.09
Average	1.14	91	11.62	80.72	0.91
Weight	634.00kg				

Table 2.0
Rheological properties of raw material, R_2

Sample No	T_{s2}	T_{c90}	M_L	M_H
	m : s	m : s	lb-in	lb-in
S_1	1:56	8:34	27.3	88.8
S_2	2:21	10:47	21.34	78.22
S_3	1:50	9:22	26.14	88.79
S_4	2:00	9:03	27.29	86.88
S_5	2:06	11:02	21.69	84.06
S_6	2:38	7:08	20.21	91.95
Average	2:08	9:19	24	86.45

Table 2.1
Physical properties of raw material, R_2

Sample No	SG	HD	TS	EAB	Moisture content
	g/cm^3	IRHD	MPa	%	wt. %
S_1	1.14	92	16.72	58.53	1.05
S_2	1.15	93	19.65	64.13	0.9
S_3	1.14	93	14.43	58.93	0.87
S_4	1.15	100	6.03	156.77	0.62
S_5	1.15	91	15.95	78	1.02
S_6	1.14	100	8.81	75.87	0.95
Average	1.14	95	13.6	82.04	0.9
Weight	752.00 kg				

Table 2.2
Rheological properties of raw material, R_3

Sample No	T_{s2}	T_{c90}	M_L	M_H
	m : s	m : s	lb-in	lb-in
S_1	2:42	8:34	18.2	91.07
S_2	2:34	8:38	19.01	93.27
S_3	2:38	8:26	18.55	92.37
S_4	2:35	8:32	17.93	91.03
S_5	2:32	8:25	19.06	91.4
S_6	3:01	8:42	16.58	92.15
Average	2:40	8:32	18.22	91.88

Table 2.3
Physical properties of raw material, R_3

Sample No	SG	HD	TS	EAB	Moisture content
	g/cm^3	IRHD	MPa	%	wt. %
S_1	1.17	79	4.68	126.83	2.08
S_2	1.17	76	4.96	190.13	1.33
S_3	1.16	84	4.23	216.67	1.06
S_4	1.14	74	4.28	181.27	1.47
S_5	1.12	79	4.3	185.63	1.2
S_6	1.12	72	3.23	156.9	1.41
Average	1.15	77	4.28	176.24	1.42
Weight	921.30 kg				

Table 2.4
Rheological properties of raw material, R_4

Sample No	T_{s2}	T_{c90}	M_L	M_H
	m : s	m : s	lb-in	lb-in
S_1	2:45	8:28	17.51	90.89
S_2	2:57	8:32	17.51	94.5
S_3	2:57	7:25	17.09	87.85
S_4	2:30	6:33	21.19	92.59
S_5	2:27	6:36	20.53	92.08
S_6	2:43	6:58	19.07	92.21
Average	2:43	7:25	18.82	91.69

Table 2.5
Physical properties of raw material, R_4

Sample No	SG	HD	TS	EAB	Moisture content
	g/cm^3	IRHD	MPa	%	wt. %
S_1	1.15	89	5.36	164.67	1.03
S_2	1.15	93	6.59	133.93	1.03
S_3	1.15	89	6.29	146.37	1.08
S_4	1.15	88	10.76	78	1.02
S_5	1.15	91	11.78	76	1.2
S_6	1.15	93	6.28	138.77	1.06
Average	1.15	91	7.84	122.96	1.07
Weight	524.00 kg				

Table 2.6
Rheological properties of raw material, R_5

Sample No	T_{s2}	T_{c90}	M_L	M_H
	m : s	m : s	lb-in	lb-in
S_1	2:35	7:34	19	91.81
S_2	2:29	6:25	21.67	89.12
S_3	1:47	9:59	27.47	87.87
S_4	2:25	8:10	24.43	91.54
S_5	2:12	8:41	19.76	87.57
S_6	2:08	9:20	20.08	87.36
Average	2:16	8:21	22.07	89.21

Table 2.7
Physical properties of raw material, R_5

Sample No	SG	HD	TS	EAB	Moisture content
	g/cm^3	IRHD	MPa	%	wt. %
S_1	1.18	92	4.9	162.57	1.03
S_2	1.18	88	5.02	144.97	1.24
S_3	1.16	87	4.85	153.73	0.84
S_4	1.18	88	6.79	93.03	1.41
S_5	1.18	93	6.54	87.87	1.25
S_6	1.19	95	7.08	65.73	0.55
Average	1.18	91	5.86	117.98	1.05
Weight	567.50 kg				

Table 2.8
Rheological properties of raw material, R_6

Sample No	T_{s2}	T_{c90}	M_L	M_H
	m : s	m : s	lb-in	lb-in
S_1	1:54	12:05	25.3	86.26
S_2	1:46	11:45	23.31	87.62
S_3	1:44	13:28	24.47	99.88
S_4	1:38	13:50	27.62	98.78
S_5	1:54	11:46	22.38	84.91
S_6	1:42	11:57	20.45	70.43
Average	1:46	12:28	23.92	87.98

Table 2.9
Physical properties of raw material, R_6

Sample No	SG	HD	TS	EAB	Moisture content
	g/cm^3	IRHD	MPa	%	wt. %
S_1	1.17	87	3.76	107.37	3.08
S_2	1.18	91	5.52	70.67	3.17
S_3	1.18	91	4.54	126.67	3.05
S_4	1.17	83	3.62	146.53	2.19
S_5	1.17	90	3.92	199.57	1.75
S_6	1.17	88	4.02	153.1	1.28
Average	1.17	88	4.23	133.98	2.42
Weight	824 kg				

Table 3.0
Rheological properties of raw material, R_7

Sample No	T_{s2}	T_{c90}	M_L	M_H
	m : s	m : s	lb-in	lb-in
S_1	1:53	12:54	24.35	97.71
S_2	1:43	13:43	25.32	102.05
S_3	1:32	12:09	23.22	108.82
S_4	2:00	13:01	22.67	85.47
S_5	2:16	11:43	19.84	78.12
S_6	2:20	12:09	17.61	79.34
Average	1:57	12:36	22.17	91.92

Table 3.1
Physical properties of raw material, R_7

Sample No	SG	HD	TS	EAB	Moisture content
	g/cm^3	IRHD	MPa	%	wt. %
S_1	1.12	76	4.51		0.99
S_2	1.13	80	5.32	103.3	1.09
S_3	1.14	77	6.8	87.33	1.24
S_4	1.12	82	4.21	107.93	0.8
S_5	1.13	73	4.57	106.4	1.34
S_6	1.11	76	3.66	137.8	1.24
Average	1.13	77	4.84	107.44	1.12
Weight	1001.5 kg				

Table 3.2
Rheological properties of raw material, R_8

Sample No	T_{s2}	T_{c90}	M_L	M_H
	m : s	m : s	lb-in	lb-in
S_1	2:22	10:36	21.83	88.63
S_2	2:38	13:10	19.97	91.21
S_3	2:33	13:58	23.1	96.96
S_4	2:27	10:30	15.45	66.03
S_5	2:30	10:11	15.04	71.52
S_6	1:56	14:09	25.78	92.25
Average	2:24	12:05	20.2	84.43

Table 3.3
Physical properties of raw material, R_8

Sample No	SG	HD	TS	EAB	Moisture content
	g/cm^3	IRHD	MPa	%	wt. %
S_1	1.19	91	5.26	96.97	1.37
S_2	1.19	90	4.87	99.2	1.87
S_3	1.19	92	5.18	94.7	0.96
S_4	1.20	100	5.06	74.53	1.43
S_5	1.19	94	4.83	99.7	1.78
S_6	1.18	89	7.91	78.67	1.59
Average	1.19	93	5.52	90.63	1.5
Weight	637.00 kg				

5.1.2 Specific gravity test result

Specific gravity/relative density is defined as the ratio of the mass of a given volume of the impermeable portion of the material at 23 ^{0}C to the mass of an equal volume of gas-free distilled or de-mineralized water at the same temperature [37]. Thus the specific gravity formula can be given as,

$$\text{Specific gravity} = \frac{\text{Weight of the material}}{\text{Weight of the equal amount of water}}$$

Or

$$\text{Specific gravity} = \frac{\text{Density of material}}{\text{Density of equal volume of water}}$$

It was apparent from the results in Tables 1.9, 2.1, 2.3, 2.5, 2.7, 2.9, 3.1 and 3.3 that specific gravity of each material got varied. Therefore, specific gravities of R_1, R_2, R_3, R_5, R_6, R_7 and R_8 lied within the ranges of 1.14 g/cm^3-1.15 g/cm^3, 1.14g/cm^3-1.15 g/cm^3, 1.12 g/cm^3-1.17 g/cm^3, 1.16 g/cm^3-1.19 g/cm^3, 1.17 g/cm^3-1.18 g/cm^3, 1.11 g/cm^3-1.14 g/cm^3 and 1.18 g/cm^3-1.20 g/cm^3 respectively. In contrast, raw material, R_4 showed the consistency with specific gravity of 1.15 g/cm^3. In comparison with each other specific gravities of some materials like R_3 lied

within a broad range whereas the range was narrow for other materials like R_1, R_2 and R_6. The range was moderate for materials of R_5, R_7 and R_8. In the case of FRC, specific gravity depends on densities of both matrix phase (calender compound) and reinforcing phase (fibers) or density of nylons. In the section, 3.4.b, it has mentioned that matrix phase of FRC constituted mainly by polymers like NR and SBR and nylons are most popular in reinforcing phase. Densities of NR, SBR, nylons generally vary between (0.91-0.93) g/cm^3, 0.94 g/cm^3 and (1.46-1.15) g/cm^3 [38] respectively. That is, NR and SBR alone have lower densities compared to nylons. However, the density of the compound is higher than that of the fibers, because of the presence of compounding ingredients including sulfur, carbon black, zinc oxide and etc. Therefore, the density and specific gravity of FRC can expected to be decreased with the increase of fiber content. However, Figure 3.1 showed that there was no any decreasing trend in specific gravities with the increase in fiber

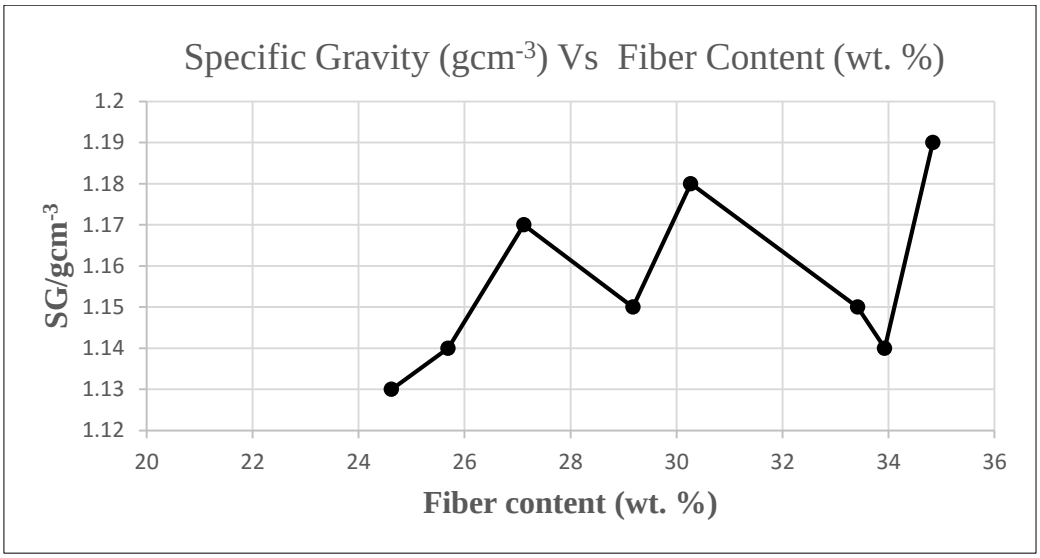


Figure 3.1 Average values of specific gravities of R_1-R_8 with fiber content (wt. %)

content.R_1, R_3, R_5 and R_8 having higher fiber contents of 33.93 %, 33.42 %, 30.27 % and 34.84 % showed specific gravities like 1.14 g/cm^3, 1.15 g/cm^3, 1.18 % and 1.19 g/cm^3. R_2, R_4, R_6 and R_7 with fiber contents of 25.69 %, 29.18 %, 27.12 % and 24.62 % showed specific gravities like 1.14 g/cm^3, 1.15 g/cm^3, 1.17 g/cm^3 and 1.13 g/cm^3 respectively. That is, materials with higher fiber contents had both high and low

specific gravities. Similarly, materials with lower fiber contents had both high and low specific gravities. Therefore it was evident that there was no any correlation between the fiber contents and specific gravities of selected eight materials. Different tire manufacturers may have used different compound compositions in their tire building and as a result of this, eight materials tested above have different densities and specific gravities. Moreover, it can be understood that fiber contents of all selected materials at the range of 24.62 % - 34.84 % had made no effects on the specific gravity of FRC. Instead, it has been mainly influenced by the density of rubber compound.

5.1.3 Hardness test result

According to the test results given in Tables 1.9, 2.1, 2.3, 2.5, 2.7, 2.9, 3.1, 3.3 hardness property was also variable within the same material and from one material to other. Results of hardness varied between the limits of (88-93) IRHD, (91-100) IRHD, (72-84) IRHD, (88-93) IRHD, (87-95) IRHD, (83-91) IRHD, (73-82) IRHD and (89-100) IRHD for materials, R_1, R_2, R_3, R_4, R_5, R_6, R_7 and R_8 respectively. Further, the majority of values for hardness of R_1, R_2, R_4, R_5, R_6 and R_8 were higher than 80 IRHD while R_3 and R_7 were having most of hardness values which were lesser than 80 IRHD. It has been mentioned in the literature that hardness of short-fiber polymer composites depends on the fiber content and hence increasing fiber content also increases the hardness values of the composites [16, 23, 27]. However, Figure 3.2 showed that there was no any correlation between the fiber content and the average hardness values of materials. According to the test results in Tables 1.9, 2.1, 2.3, 2.5, 2.7, 2.9, 3.1 and 3.3, R_2 claimed for the highest average hardness which was recorded as 95 IRHD. But the fiber content of R_2 was low in comparison with that of other materials including R_1, R_3, R_4, R_5, R_6 and R_8. Even though both R_3 and R_7 had the same lowest average hardness values which was 77 IRHD, fiber content of R_3 was higher than that of R_2, R_4, R_5, R_6 and R_7 and the fiber content of R_7 was the lowest which was recorded as 24.62 %. Therefore, other factors which affect the hardness of materials should also considered. Hardness, similar to maximum torque in a rheograph is influenced by elastic modulus and

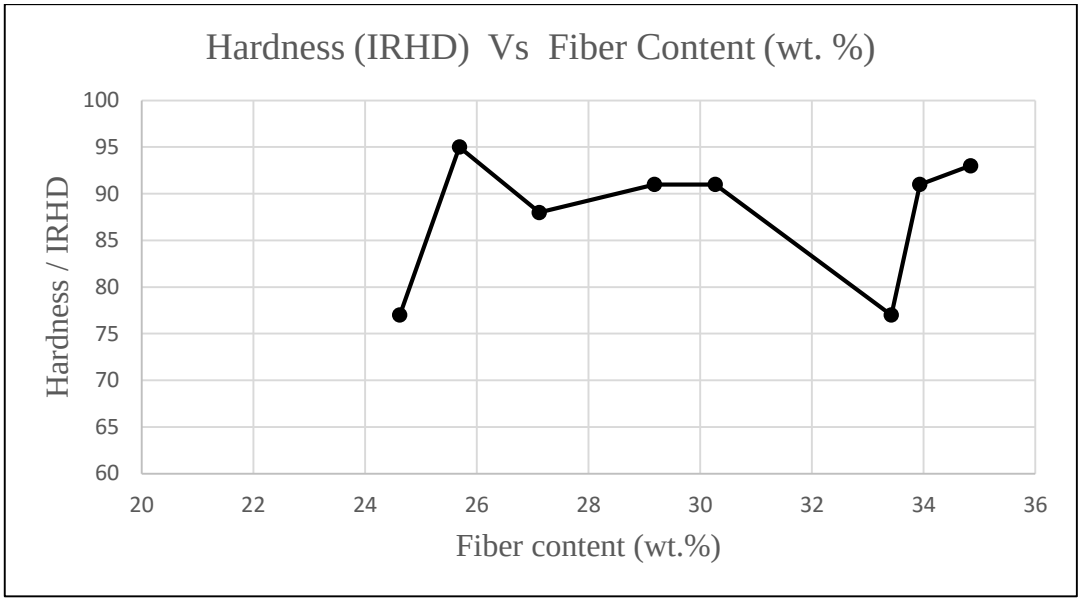


Figure 3.2 Average values of hardness of R_1-R_8 with fiber content (wt. %)

related to crosslink density [2]. In addition, hardness of a compound is determined by the type and amounts of reinforcing fillers such as carbon black, softeners used and by the use of crosslinked resin system used [2, 3].

5.1.4 Tensile test result

Test results in Tables 1.9, 1.8, 2.1, 2.3, 2.5, 2.7, 2.9, 3.1 and 3.3 showed that there was an inconsistency in values of tensile strength and elongation within the same material and from one material to the other. Tensile strength of R_1, R_2, R_3, R_4, R_5, R_6, R_7 and R_8 materials varied between (6.81-13.46) MPa, (6.03-19.65) MPa, (3.23-4.96) MPa, (5.36-11.78) MPa, (4.85-7.08) MPa, (3.62-5.52) MPa, (3.66-6.80) MPa and (4.83-7.91) MPa. Limits between which elongation at break of materials (R_1-R_8) varied were (61.73-127.20) %, (58.53-156.77) %, (126.83-216.67) %, (76-164.67) %, (65.73-162.57) %, (70.67-199.57) %, (87.33-137.80) % and (74.53-99.70) %. In literature, it has mentioned that addition of short fibers leads to the slight increase of tensile strength but it decreases the elongation at break of the compound [27, 28]. Figure 3.3 and Figure 3.4 show the variation of average tensile strength and average elongation at break vary with the fiber contents of tested eight materials (R_1-R_8). According to the figure 3.3, R_2 had the highest average tensile

strength which was recorded as 13.60 MPa. But its fiber content was 25.69 % which was lower than the fiber contents of R_1, R_3, R_4, R_5 and R_6. In contrast, R_1 having a fiber content of 33.93 % which was lower only for the fiber content of 34.84 % of R_8 showed tensile strength of 11.62 MPa which was lower than the tensile strength of R_2. Furthermore, R_8 material having the highest fiber content of 34.84 % among tested materials, recorded a tensile strength of 5.52 MPa which was slightly higher than the lowest tensile strength, 4.23 MPa obtained for R_6.

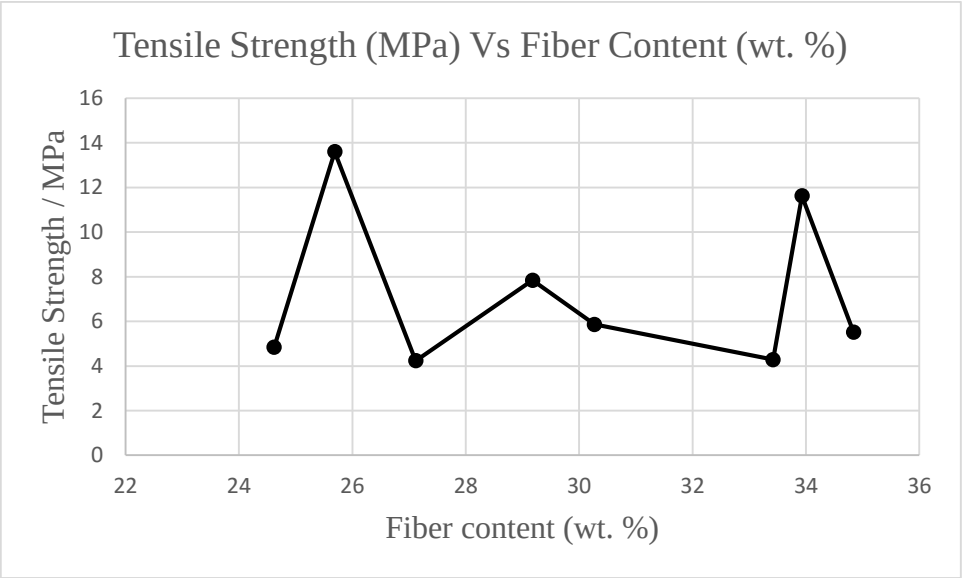


Figure 3.3 Average values of tensile strength of R_1-R_8 with fiber content (wt. %)

According to the Figure 3.4, R_3 had the highest average elongation at break value, even though it had a high fiber content like 33.42 % which was lower only to 33.93 %, fiber content of R_1 and 34.84 %, fiber content of R_8. Even though the fiber content of R_1 and R_2 were 33.93 % and 25.69 %, there was only a slight difference between their values for elongation at break which were 80.72 % and 82.04 %. However, R_1 and R_8 having high fiber contents showed lower average values for elongation at break like 80.72 % and 90.63 % when average elongation at break values of R_3, R_4, R_5, R_6 and R_7 are concerned.

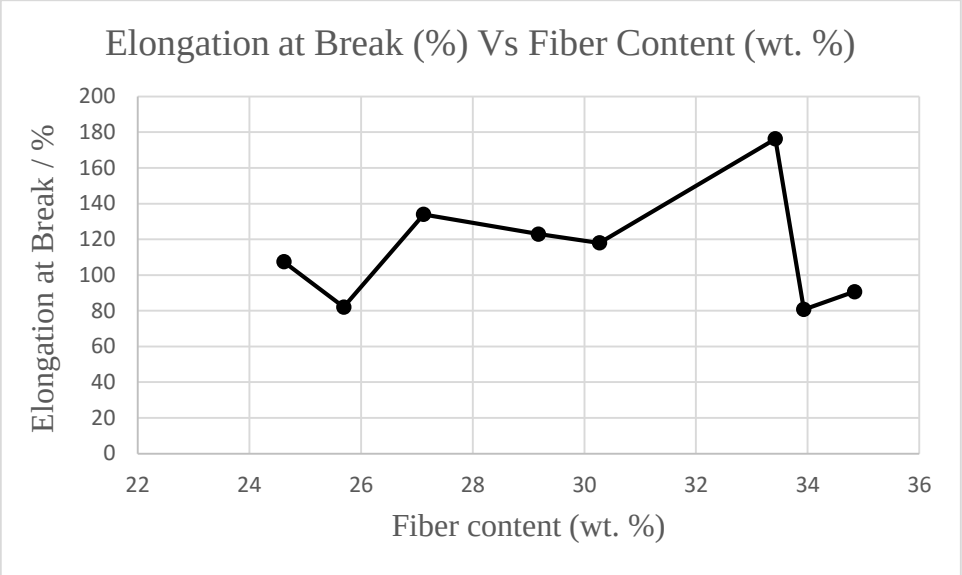


Figure 3.4 Average values of elongation at break of R_1-R_8 with fiber content (wt. %)

Finally, it was obvious that average results obtained for tensile strength and elongation at break did not correlate with fiber contents of selected materials. However, in the case of fiber reinforced polymer composites, lower fiber contents gives lower mechanical strength. At low fiber content, the matrix is not restrained by enough fibers and highly localized strains occur in the matrix at low strain levels, causing the bond between fiber and rubber to break, leaving the matrix diluted by non-reinforcing, de-bonded fibers. In contrast, at high fiber contents, the matrix is sufficiently restrained and the stress is more evenly distributed, thus the reinforcement effect outweighs the dilution effect and tensile properties gradually improve to give a strength higher than that of the matrix [21]. In addition to increased fiber content, orientation of fibers leads stress to distribute uniformly and thus the tensile properties get improved [21, 28]. Fibers in short fiber-polymer composites can act as reinforcers but short fiber reinforcement is insufficient to compete with continuous cord reinforcement [21]. Additionally, good adhesion between the fiber and the matrix and the proper dispersion of fibers (homogeneous mixing) are also considered to be an important factors that determine an efficient stress transfer which in turn bring about high strength in composites [21, 28]. Tensile strength and elongation at break of short nylon fiber reinforced natural rubber matrix were studied and the results obtained at both longitudinal and transverse direction of

fibers up to about 30 p.p.h.r loading of fibers were superior than results obtained for friction cords [28]. Therefore, it can be suggested that above inferior tensile properties resulted were due to the lack of fiber orientation, poor dispersion of fibers, poor adhesion between fibers and matrix associated with FRC.

5.1.5 Moisture test result

As it has been described in section, 3.4.a, tensile properties would drop if moisture is present at the temperatures which tires are cured [7]. Therefore, moisture content in FRC is considered to be a very important parameter in determining its quality before applying for products, especially for tires. As per the results of moisture contents given in Tables 1.9, 2.1, 2.3, 2.5, 2.7, 2.9, 3.1 and 3.3 figures for moisture content got varied within the same material and from one material to the other as in the case of other properties like specific gravity, hardness and tensile properties. Because of the high sensitivity of nylon cords, moisture can easily be absorbed into FRC when they are exposed to the environment with high relative humidity [7]. Therefore, fiber contents, in this case it is nylons, directly effects on the moisture content of FRC. The presence of fibers like nylons in high percentages in FRC can be expected to give high content of moisture and vice versa. Figure 3.5 showed the variation of average moisture content of R_1-R_8 with their fiber content. It showed that moisture content got fluctuated and hence there was no any increasing trend in moisture content with the increase of fiber content. Even though R_6 had fiber content of 27.12 % which was lower than that of R_1, R_3, R_4, R_5 and R_8 and which was higher than that only of R_2 and R_7, it had the highest moisture content of 2.42 % compared to that of remaining seven materials including R_1, R_2, R_3, R_4, R_5, R_7 and R_8. Next highest value for moisture content was 1.50 % obtained for R_8 which the material was having highest fiber content, 34.84 %. Therefore, in this case, other factors like relative humidity of the environment during both the storage of rubberized nylon friction in yards and storage after processing them into FRC may have influenced the moisture content of R_6. Undoubtedly, there is a greater possibility to absorb moisture by nylons even at lower percentages when the environment has a high relative humidity.

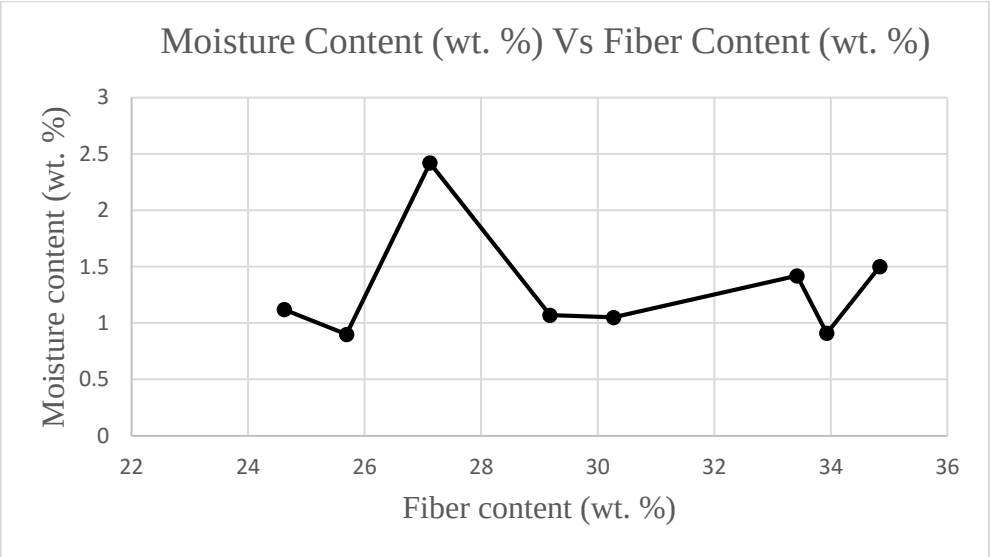


Figure 3.5 Average values of moisture content of R_1-R_8 with fiber content (wt. %)

5.1.6 Rheology test result.

Tables 1.8, 2.0, 2.2, 2.4, 2.6, 2.8, 3.0 and 3.2 show the test results for parameters such as Ts2, Tc 90, M_L and M_H obtained for 48 samples. Scorch time indicates the point where rubber compounds starts to crosslink [2] and it is measured as the time required for the torque to increase by one and two units. Usually, two measurements known as t_{s1} and t_{s2} can be obtained with rheographs as scorch times. t_{s1} is the time required to rise in torque by on unit, while the time required to rise in torque by 2 unit is known as t_{s2}. However, the results only for t_{s2} were recorded in this study. The time interval for the torque to achieve 90% of its increase from M_L to M_H is known as t_{c90}. The rise in torque is considered to be proportional to the rise in crosslink density [3] and it represents the time required to complete 90% of cross linking reaction. t_{c90} slightly gets decreased with the increase of fiber loading and the change in t_{s2} is also slight [28]. In order to find out whether there is any correlation between t_{s2} and t_{c90} values and fiber content, average values of t_{s2} and t_{c90} of FRC were plotted against fiber contents of R_1-R_8 (Figure 3.6). Average of t_{s2} and t_{c90} values get fluctuated with the fiber content of R_1-R_8 and hence there is no any decreasing trend in average t_{s2} and t_{c90} values with the increase of fiber contents.

M_L measured in the initial part of the curve is considered as a measure of viscosity of the compound [2, 3, 28]. In other words, it indicates how well the material is liable to flow under processing conditions [3]. Thus increase in viscosity relates to increase in M_L. For an instance, presence of fiber and fillers such as carbon black contribute to the increase in M_L [2, 28]. Furthermore, M_L value of fiber-filled compounds is higher than that of the carbon black-filled compounds [28]. As in the case of t_{s2} and t_{c90}, there is no correlation between the average M_L values and fiber contents of R_1-R_8 (Figure 3.7).

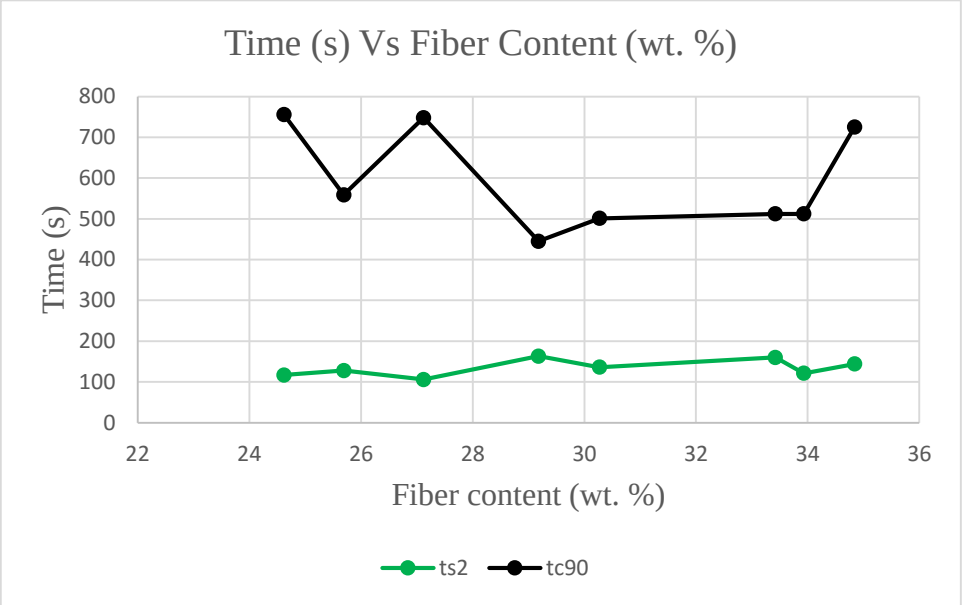


Figure 3.6 Average values of t_{s2} and t_{c90} of R_1-R_8 with fiber content (wt. %)

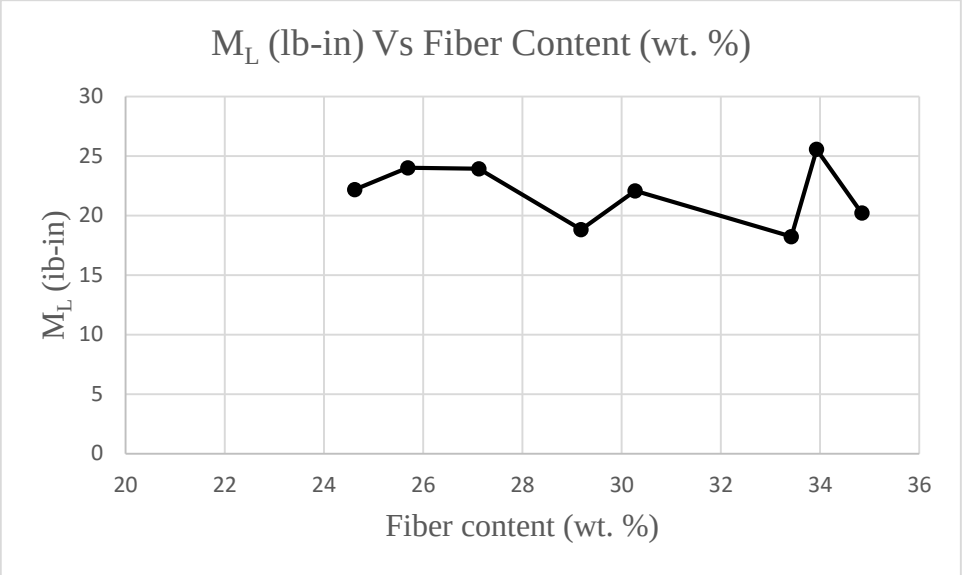


Figure 3.7 Average values of M_L of R_1-R_8 with fiber content (wt. %)

Another important parameter which can be obtained with rheographs is the M_H and it correlates only roughly with the compound hardness or stiffness [2, 3]. However, Figure 3.8 shows that average MH values cannot be compared with average hardness values as all figures get fluctuated. Even though R_1 had the highest M_H of 96.49 lb-in, its average hardness was 91 IRHD which was lower average hardness values of R_2, R_4, R_5 and R_8. Whereas R_2 had the highest hardness of 95 IRHD and low average M_H value which was lower than that of R_1, R_3, R_4, R_5, R_6 and R_7.

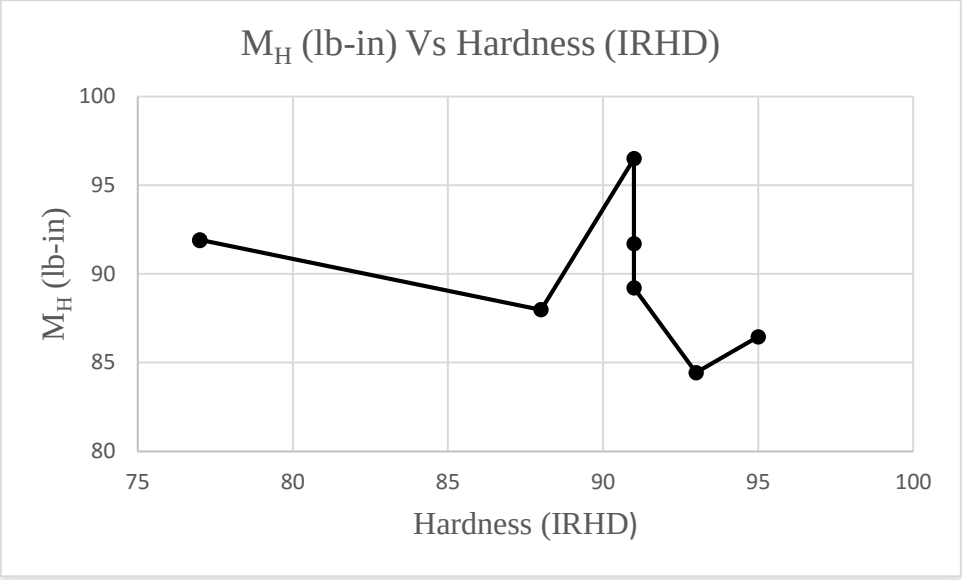


Figure 3.8 Average M_H values with average hardness values of R_1-R_8

According to the figures given in Tables 1.8, 2.0, 2.2, 2.4, 2.6, 2.8, 3.0 and 3.2, results of Ts2, Tc90, M_L and M_H varied within the same bulky material and from one material to the other. And it was apparent that variation was large for some materials and it was small for other materials. Therefore it can be suggested that these variable rheological properties are due to the uneven distribution of ingredients including rubber, sulphur, accelerators and activators which contribute the formation of crosslinks in FRC. Variation in every property was the major drawback associated with FRC. Usually, bulky materials used to produce FRC consist of fabric scraps from the production of a large variety of pneumatic tires. As a result, different compounds compositions may have contributed to the formation of the whole bulky material. Due to the inconsistency in each and every ingredient and lack of fiber orientation, poor dispersion of fibers in the rubber matrix, poor adhesion between fiber and rubber matrix, expected correlation between the fiber content of each material and properties such as specific gravity, hardness, tensile strength, elongation at break, moisture content and rheological properties could not be observed.

5.2. Standardization of Friction Cords

Table 1.0 in section 4.3, preparation of blends and the collection of samples from blends for testing (No: 1-No: 5) were described. Test results of specific gravity (SG), hardness (HD), tensile strength (TS), elongation at break (EAB) and moisture content relevant to blends (No: 1-No: 5) were given in Tables (3.4-3.8).

Table 3.4
Properties of blend No: 1

Sample No	SG	HD	TS	EAB	Moisture content
	g/cm^3	IRHD	MPa	%	wt. %
S_1	1.17	87	3.43	130.8	0.93
S_2	1.16	80	4.1	130.57	1.04
S_3	1.16	84	4.12	135.5	1.15
S_4	1.16	90	4.22	135.63	0.98
S_5	1.15	88	4.06	174.63	1.08
S_6	1.16	83	5.18	92.23	1.14
Average	1.16	85	4.19	133.23	1.05

Table 3.5
Properties of blend No: 2

Sample No	SG	HD	TS	EAB	Moisture content
	g/cm^3	IRHD	MPa	%	wt. %
S_1	1.16	93	5.89	121.23	0.98
S_2	1.15	89	7.02	92.71	1.01
S_3	1.16	90	10.12	81.84	1.52
S_4	1.14	88	4.23	55.93	0.71
S_5	1.14	91	9.27	63.41	0.86
S_6	1.17	85	11.12	135.94	0.94
Average	1.15	89	7.94	91.84	1.00

Table 3.6
Properties of blend No: 3

Sample No	SG	HD	TS	EAB	Moisture content
	g/cm^3	IRHD	MPa	%	wt. %
S_1	1.14	88	9.86	67.45	1.11
S_2	1.14	92	5.42	113.94	0.87
S_3	1.16	85	4.75	132.12	0.98
S_4	1.15	90	14.65	74.62	0.51
S_5	1.17	82	8.83	53.81	0.23
S_6	1.15	95	10.12	76.93	1.32
Average	1.15	89	8.94	86.48	0.84

Table 3.7
Properties of blend No: 4

Sample No	SG	HD	TS	EAB	Moisture content
	g/cm^3	IRHD	MPa	%	wt. %
S_1	1.15	89	11.72	148.43	0.83
S_2	1.15	81	7.81	78.43	1.15
S_3	1.13	79	5.83	125.21	0.74
S_4	1.16	80	9.47	52.65	0.94
S_5	1.15	88	12.61	133.64	1.78
S_6	1.14	84	14.63	111.91	1.12
Average	1.15	84	10.35	108.38	1.09

Table 3.8
Properties of blend No: 5

Sample No	SG	HD	TS	EAB	Moisture content
	g/cm^3	IRHD	MPa	%	wt. %
S_1	1.16	94	9.21	95.24	1.32
S_2	1.14	86	8.93	124.39	0.97
S_3	1.15	84	10.95	79.64	0.58
S_4	1.14	91	5.64	141.56	0.99
S_5	1.13	95	7.82	81.92	1.31
S_6	1.15	92	8.39	90.75	0.82
Average	1.15	90.33	8.49	102.25	1.00

100 g of R_2 sample, 100 g of R_3 sample and 100 g of R_5 sample were mixed in 1:1:1 ratio, to prepare blend No: 1. Average specific gravities of R_2, R_3 and R_5 were 1.14 gcm^{-3}, 1.15 gcm^{-3} and 1.18 gcm^{-3} respectively before preparing the blend. Therefore, the average specific gravity of R_2 was low compared to that of both R_3 and R_5. But, once the blend No: 1 was prepared, average specific gravity of the blend was 1.16 gcm^{-3}. Figure 3.9 shows the variation in specific gravity with increasing weight of R_2 sample (from blend No: 1 to blend No: 5). It was evident that average specific gravity of 1.16 gcm^{-3} of blend No: 1 decreased up to 1.15 gcm^{-3}withthe addition of 200 g of R_2 sample. That specific gravity of 1.15 gcm^{-3}

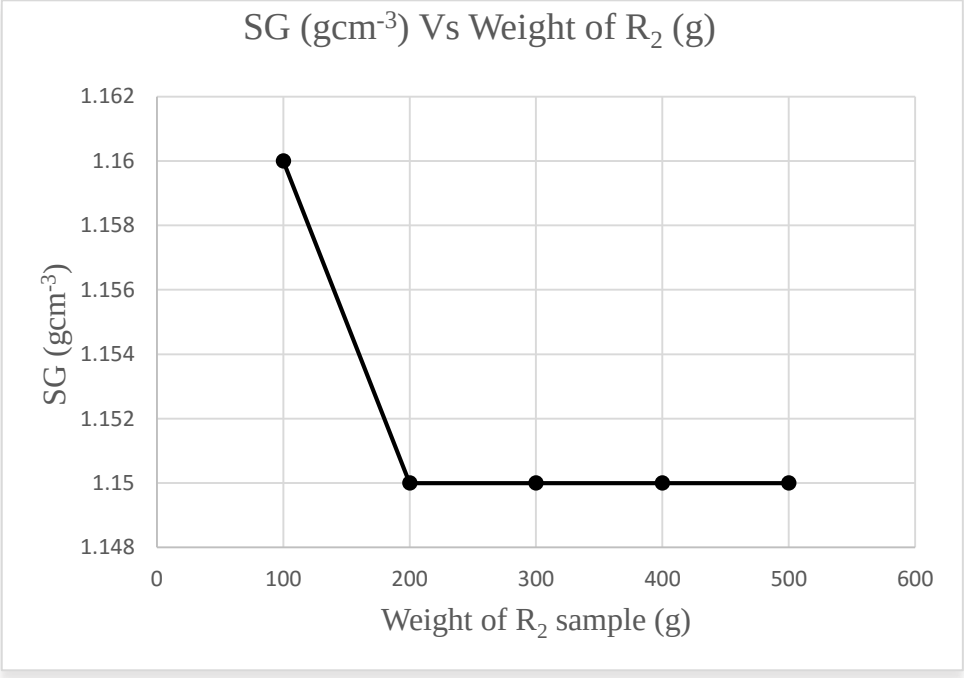


Figure 3.9 Average specific gravities of blends (No: 1-No: 5) with weight of R_2 sample

remained constant even in the next three blends with the addition of 300 g, 400 g and 500 g of R_2 sample. Therefore, it was obvious that specific gravity of the blend got decreased gradually with the increase of weight fraction of sample having low specific gravity, in this case it was R_2 sample.

R_2 sample, R_3 sample and R_5 sample mixed in 1:1:1 ratio to prepare blend No: 1 had average hardness of 95 IRHD, 77 IRHD and 91 IRHD respectively prior to blending. R_2 had the highest average hardness of 95 IRHD. But the average

Figure 4.0 Average hardness of blends (No: 1-No: 5) with weight of R_2 sample

hardness of the prepared blend was 85 IRHD. Figure 4.0 shows the variation of average hardness of blend No: 1-blend No: 5 with the increased weight fraction of R_2 sample. Average hardness of 85 IRHD of blend No: 1 was increased up to 89 IRHD with the increase of weight of R_2 sample in blend No: 2 and that value was remained same in the blend No: 3 in where 300 g of R_2 sample was mixed. 89 IRHD value was suddenly decreased up to 84 IRHD with the addition of 400 g of R_2 sample in blend No: 4. Average hardness steepened up to 90 IRHD with mixing 500 g of R_2 sample in blend No: 5. Overall, average hardness of blend No: 1-blend No: 5 got increased from 85 IRHD in blend No: 1 to 90 IRHD in blend No: 5 except minor deviations like 84 IRHD in blend No: 4, with the increased weight of R_2 sample.

Average tensile strength of R_2, R_3 and R_5 used to prepare blend No: 1 was 13.60 MPa, 4.28 MPa and 5.86 MPa respectively. Therefore, R_2 had the highest

hardness before preparing the blend. Average tensile strength of the blend No: 1 was 4.19 MPa. Figure 4.1 shows that that value was increased up to 10.35 MPa in where 400 g of R_2 sample mixed. But 10.35 MPa was dropped up to 8.94 MPa in blend No: 5. 82.04 %, 176.24 % and 117.98 % were the average values of elongation at break

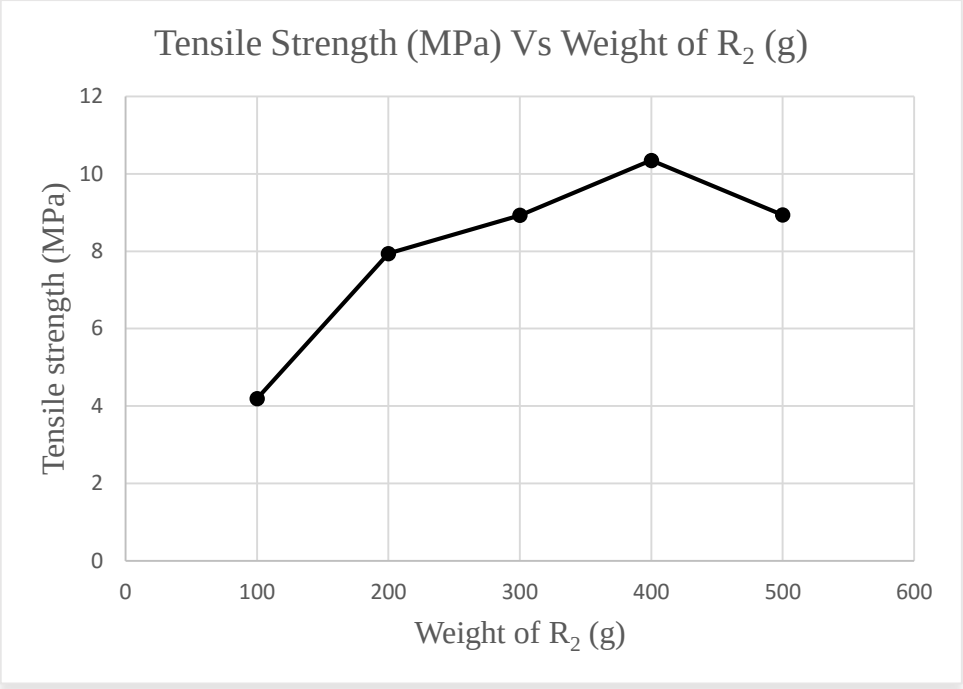


Figure 4.1 Average tensile strength of blends (No: 1-No: 5) with weight of R_2 sample.

of R_2, R_3 and R_5 respectively. Among them, R_3 had the highest elongation at break which was 176.24 %. When they were mixed together in 1:1:1 ratio, average elongation at break of blend No: 1 was 133.23 %. And that value was gradually decreased up to 86.47 % in where R_2, R_3 and R_5 were mixed in 3: 1: 1 ratio to prepare blend No: 3. After that average elongation at break value was got increased up to 108.37 % in blend No: 4. Then, the elongation at break got slightly decreased and finally average elongation at break of blend No: 5 was 102.25 % (Figure 4.2). In literature it has mentioned that slight increase of tensile strength and the decrease of elongation at break of the compound could be observed with the addition of short fibers [28]. In comparing Figure 4.1 with Figure 4.2, it was obvious that average

elongation at break got decreased with the increase of tensile strength from blend No: 1 to blend No: 3. But such a relationship could not be observed from blend No: 4 to blend No:5. Moreover, 64.13 % was the lowest value among the values of elongation at break of R_2, R_3 and R_5 and highest value of elongation at break among them was 216.67 % before blending. Therefore, it was expected that elongation at break values of these five blends would be within 64.13 %-216.67 %. However, values for elongation at break which were lower than 64.13 % such as 55.93 % in blend No: 2, 53.81 % in blend No: 3 and 52.65 % in blend No: 4 were obtained.

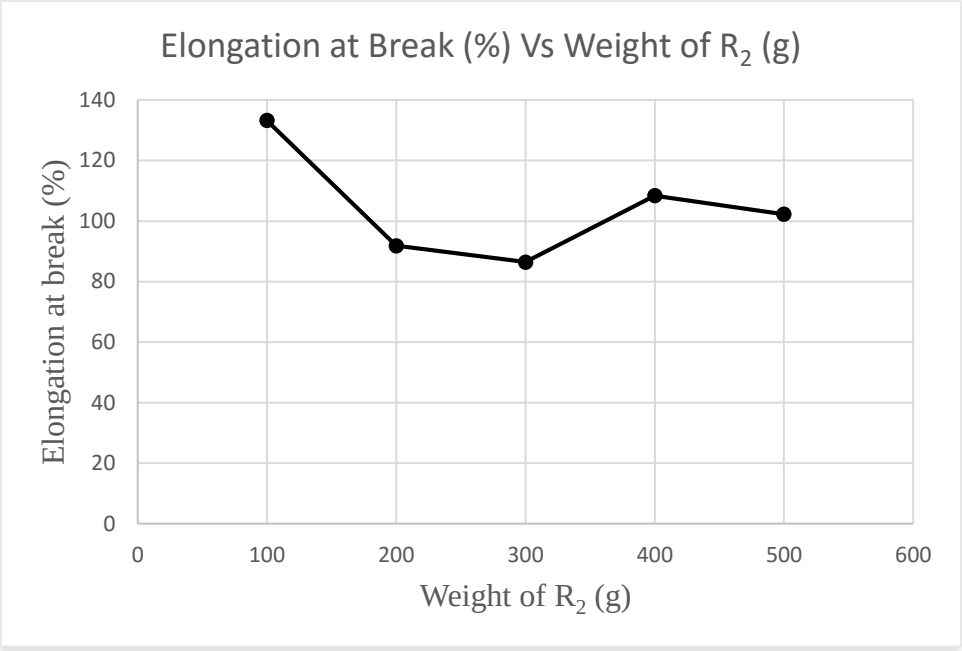


Figure 4.2 Average elongation at break of blends (No: 1-No: 5) with weight of R_2 sample

Average moisture contents of R_2, R_3 and R_5 were 0.90 %, 1.42 % and 1.05 % respectively prior to blending. Therefore, R_2 had the lowest moisture content among them. The average moisture content of the blend No: 1 in where R_2, R_3 and R_5 were mixed in 1:1:1 ratio, was 1.05 %. It could be expected moisture content getting lower values with increasing weight of R_2 sample, because R_2 had the lowest value. However the average moisture content fluctuated with the increase of weight of R_2 sample from blend No: 1 to blend No: 5 (Figure 4.3). Since moisture content mainly depends on fiber content/nylon content, it could be explained that this

fluctuated figures resulted due to non-homogeneous mixing of fibers in the matrix phase of friction cords.

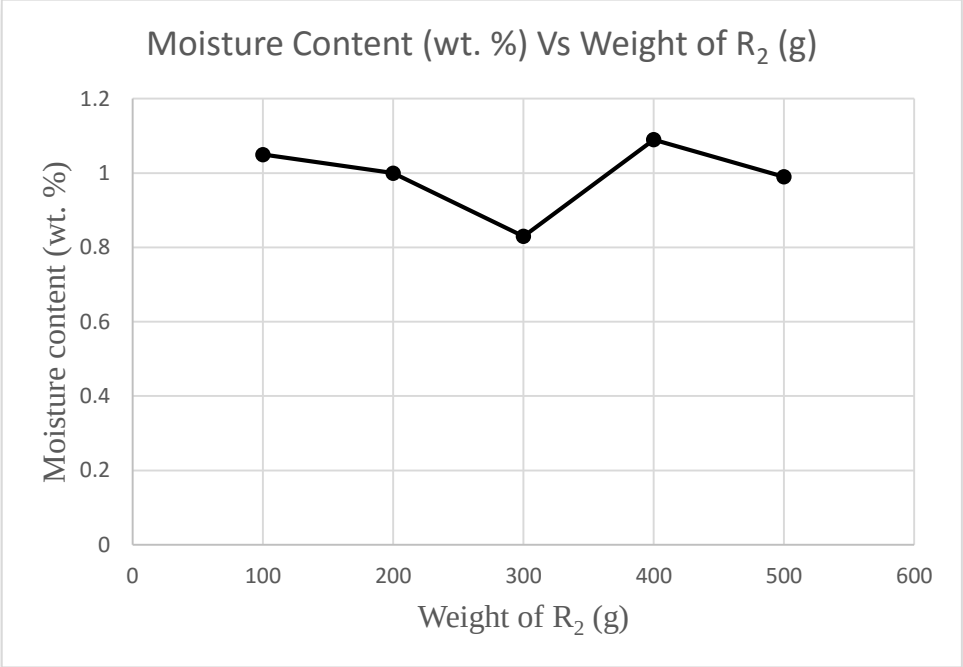


Figure 4.3 Average moisture content of blends (No: 1-No: 5) with weight of R_2 sample

According to the test results relevant to blends (No: 1-No: 5), given in Tables (3.4-3.8),average specific gravity of blend No: 1, blend No: 2, blend No: 3, blend No: 4 and blend No: 5 were varied between (1.15-1.17) gcm^{-3}, (1.14-1.17) gcm^{-3}, (1.14-1.17) g/cm^{-3}, (1.13-1.16) gcm^{-3} and (1.13-1.16) gcm^{-3} respectively. That is, lower specific gravities like 1.12 gcm^{-3} of material, R_3 and higher specific gravities like 1.18 gcm^{-3} and 1.19 gcm^{-3} have been disappeared once the blends were prepared. In the case of hardness property, limits between which hardness lied were (80-90) IRHD, (85-93) IRHD, (85-95) IRHD, (79-89) IRHD and (84-95) IRHD for blend No: 1, blend No: 2, blend No: 3, blend No: 4 and blend No: 5 respectively. Therefore, it was clearly seen that higher hardness values like 100 IRHD of R_2 and lower hardness values of 72 IRHD, 74 IRHD and 76 IRHD of R_3 have been cancelled out when R_2, R_3 and R_5 were combined to prepare blends. In the same way, tensile strength of above 14.43 MPa like 15.95 MPa, 16.72 MPa and 19.65

MPa of R_2, high elongation at break values like 181.27 %, 185.63 %, 190.13 % and 216.67 % of R_3 and values of moisture content above 2 % of R_3 like 2.08 % have been cancelled out because of blending. As a result of this, tensile strength of blend No: 1, blend No: 2, blend No: 3, blend No: 4 and blend No: 5 lied in the range of (3.43-5.18) MPa, (4.23-11.12) MPa, (4.75-14.65) MPa, (5.83-14.63) MPa and (5.64-10.95) MPa respectively and elongation at break lied in the range of (92.23-174.63) %, (55.93-135.94) %, (53.81-132.12) %, (52.65-148.43) % and (79.64-141.56) % respectively. Moreover, moisture content of five blends varied between (0.93-1.15) %, (0.71-1.52) %, (0.23-1.32) %, (0.74-1.78) % and (0.58-1.32) %. Therefore these figures were a clear indication that scattered data for properties of materials, R_2, R_3 and R_5 prior to blending have come closer after blending. Table 4.8shows a typical example for specifications of friction cords commonly used for solid tire base layer at US Lanka Rubber Solutions Private Limited, Seeduwa. In comparison with each other, data ranges for specific gravity, hardness, tensile strength, elongation at break and moisture content of blend No: 1 were matched with the specification given in Table 4.8.

Test results of specific gravity, hardness, tensile strength, elongation at break and moisture content relevant to blends (No: 6-No: 9) are given in Tables (3.9-4.2)

Table 3.9
Properties of blend No: 6

Sample No	SG	HD	TS	EAB	Moisture content
	g/cm^3	IRHD	MPa	%	wt. %
S_1	1.16	85	8.03	143.76	1.21
S_2	1.15	88	7.91	150.94	1.05
S_3	1.16	89	5.69	94.82	1.13
S_4	1.16	90	13.82	75.43	1.20
S_5	1.16	86	7.54	142.85	0.86
S_6	1.17	87	6.87	127.13	0.98
Average	1.16	88	8.31	122.49	1.07

Table 4.0
Properties of blend No: 7

Sample No	SG	HD	TS	EAB	Moisture content
	g/cm^3	IRHD	MPa	%	wt. %
S_1	1.17	90	5.82	132.56	0.81
S_2	1.16	89	4.46	123.42	1.31
S_3	1.18	88	7.83	93.59	0.73
S_4	1.15	93	5.69	105.47	1.03
S_5	1.16	85	10.13	67.88	0.94
S_6	1.17	86	4.58	112.79	1.02
Average	1.17	89	6.42	105.95	0.97

Table 4.1
Properties of blend No: 8

Sample No	SG	HD	TS	EAB	Moisture content
	g/cm^3	IRHD	MPa	%	wt. %
S_1	1.18	84	6.72	119.23	1.24
S_2	1.16	88	5.24	108.54	1.01
S_3	1.17	86	6.53	99.76	0.95
S_4	1.17	89	7.79	88.54	1.11
S_5	1.16	90	8.11	150.32	1.12
S_6	1.16	92	5.93	85.74	0.85
Average	1.17	88	6.72	108.69	1.05

Table 4.2
Properties of blend No: 9

Sample No	SG	HD	TS	EAB	Moisture content
	g/cm^3	IRHD	MPa	%	wt. %
S_1	1.17	95	9.32	132.43	0.56
S_2	1.18	90	7.41	111.55	1.23
S_3	1.16	89	5.21	92.71	0.91
S_4	1.17	93	4.93	100.15	0.74
S_5	1.17	86	6.89	115.68	1.12
S_6	1.16	95	5.88	98.87	1.33
Average	1.17	91	6.61	108.57	0.98

Average specific gravity of R_5 sample was 1.18 gcm^{-3} which was higher than that of R_2 and R_3 samples. When R_2, R_3 and R_5 were mixed in 1:1:1 ratio, average specific gravity of the blend No: 1 was 1.16 gcm^{-3}. That is, with the addition of 100 g of R_5 sample, resulted average specific gravity of the blend was 1.16 gcm^{-3}. It was expected to increase that value with the addition of 200 g of R_5 sample in blend No: 6, because R_5 had the highest average specific gravity. But 1.16 gcm^{-3} remained constant even in the blend No: 6. However, the value increased up to 1.17 gcm^{-3}, with the addition of 300 g in blend No: 7. 1.17 gcm^{-3} also remained constant after mixing 400 g and 500 g of R_5 sample in both blend No: 8 and blend No: 9 respectively (Figure 4.4).Therefore, it was evident that there was a possibility to move the average specific gravity of a blend from a lower value to higher value by increasing the weight fraction of a component / a sample, having high specific gravity.

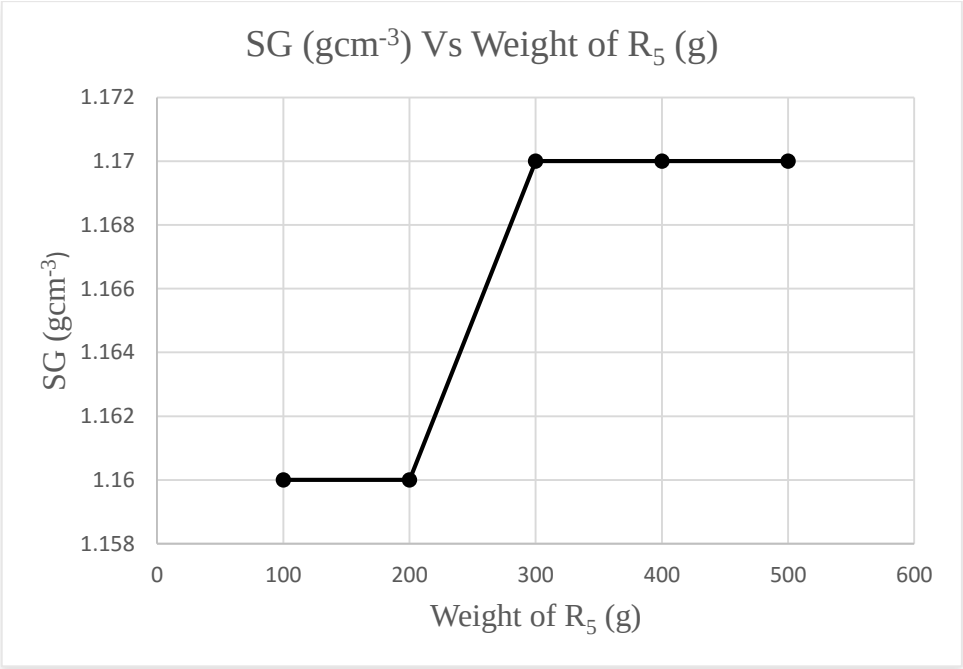


Figure 4.4 Average specific gravity of blends (No: 1 and No: 6-No: 9) with weight of R_5 sample

Average hardness of sample R_5 was 91 IRHD prior to mixing with R_2 and R_3 of which hardness values were 95 IIRHD and 77 IRHD respectively.

Therefore, R_5 had the medium average hardness value in compare with that of both R_2 and R_3. Average hardness of the blend No: 1 in where R_2, R_3 and R_5 were mixed in 1:1:1 ratio,was 85 IRHD. According to the Figure 4.5, 85 IRHD at 100 g of R_5

Figure 4.5 Average hardness of blends (No: 1 and No: 6-No: 9) with weight of R_5 sample

sample was risen up to 88 IRHD at 200 g of R_5 sample and then to 89 IRHD at 300 g of R_5 sample. However hardness value once again got decreased up to 88 IRHD at 400 g of R_5 sample then followed by increasing of average hardness up to 91 IRHD at 500 g of R_5 sample. Therefore, gradual increase in average hardness in the blend with the increased weight fraction of a sample, having considerably high hardness could not be seen. Instead, some deviations such as, in this case, drop of average hardness up to 88 IRHD at 400 g of R_5 sample could be observed.

Average tensile strength of the blend No: 1 was 4.19 MPa. This value at 100 g of R_5 sample was increased up to 8.31 MPa at 200 g of R_5 and then followed by decreasing up to 6.42 MPa at 300 g of R_5. There was a slight increase of tensile strength up to 6.72 MPa at 400 g of R_5. Eventually, the average tensile

strength was 6.60 MPa, when 500 g of R_5 sample was mixed to prepare blend No: 9. Therefore, it was understood from the Figure 4.6 that there was no any gradual decrease or increase of tensile strength with the increased weight fraction of R_5, having a medium average tensile strength value. Instead fluctuated figures resulted.

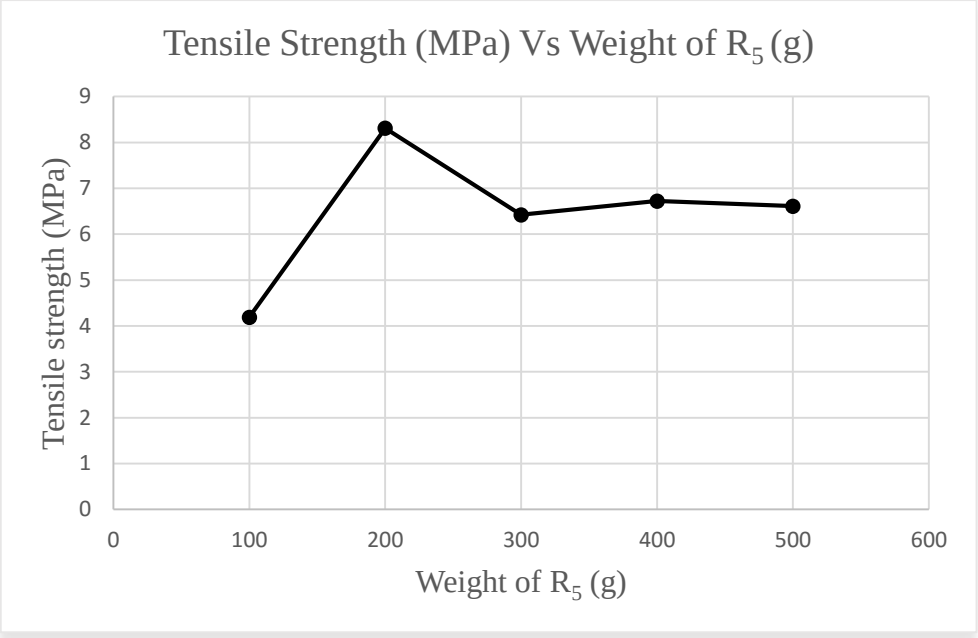


Figure 4.6 Average tensile strength of blends (No: 1 and No: 6-No: 9) with weight of R_5 sample

Average elongation at break of the blend No: 1 was 133.23 %. That value got gradually decreased and reached up to 105.95 % with the mixing of 300 g of R_5 sample to prepare blend No: 7. 105 95 % slightly got increased up to 108.68 % at 400 g of R_5 and the followed by reaching up to 108.57 % at 500 g of R_5 sample (Figure 4.7).

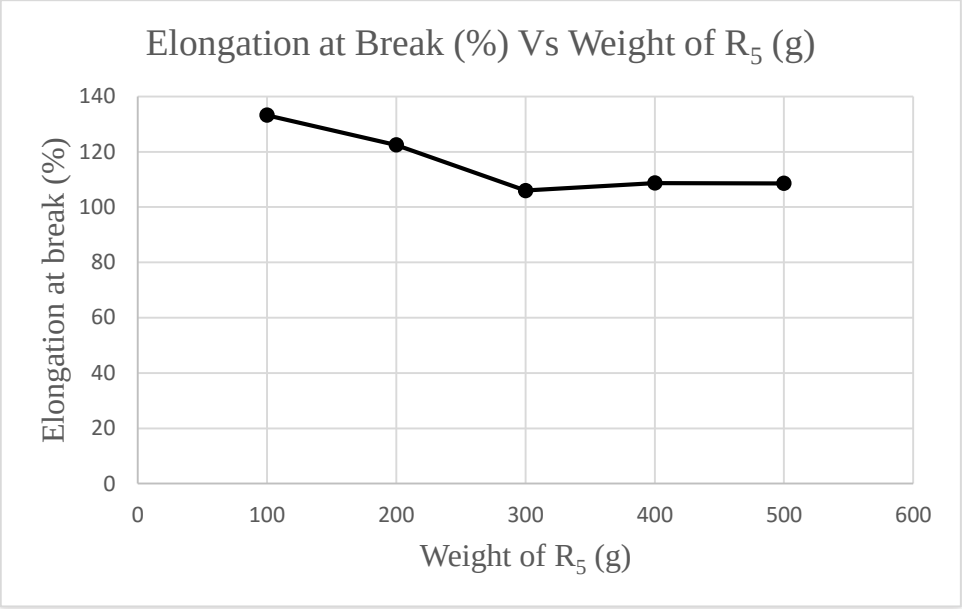


Figure 4.7 Average elongation at break of blends (No: 1 and No: 6-No: 9) with weight of R_5 sample

Average moisture content of both blend No: 1 and R_5 was 1.05 %. As it has been shown in Figure 4.8, average moisture content of blends got fluctuated as 1.05 % at 100 g of R_5, 1.07 % at 200 g of R_5, 0.97 % at 300 g of R_5, 1.05 % at 400 g of R_5 and 0.98 % at 500 g of R_5 in blends such as blend No: 1, blend No: 6, blend No: 7, blend No: 8 and blend No: 9 respectively.

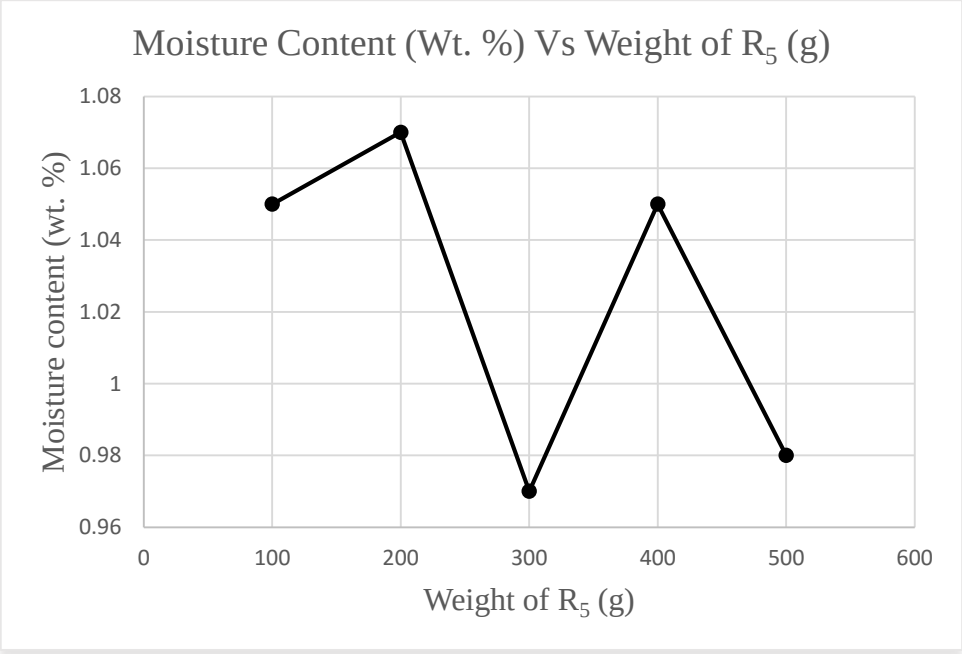


Figure 4.8 Average moisture content of blends (No: 1 and No: 6-No:9) with weight of R_5 sample

As per the results of blends (No: 6-No: 9) given in Tables (3.9-4.2), specific gravities such as 1.12 gcm^{-3} of R_3, 1.14 gcm^{-3} of R_2 and R_3 and 1.19 gcm^{-3} of R_5 were not obtained with blend No: 6, blend No: 7, blend No: 8 and blend No: 9. Therefore, specific gravity of these four blends (No: 6-No: 9) were in the limits of (1.15-1.17) gcm^{-3}, (1.15-1.18) gcm^{-3}, (1.16-1.18) gcm^{-3} and (1.16-1.18) gcm^{-3}. Further, hardness above 95 IRHD such as 100 IRHD and figures for hardness below 84 IRHD such as 72 IRHD, 74 IRHD, 76 IRHD and 79 IRHD of R_3 were also not obtained with these four blends. Ranges for hardness of four blends were (85-90) IRHD, (85-93) IRHD, (84-92) MPa and (86-95) IRHD. 13.82 MPa was the highest tensile strength obtained for blend No: 8 and it was the highest value among other three blends including blend No: 6, blend No: 7 and blend No: 9, whereas lowest among all four blends was 4.46 MPa. Even though R_2 had values for tensile strength above 13.82 MPa such as 14.43 MPa, 15.95MPa, 16.72 MPa and 19.65 MPa and values below 4.46 MPa such as 3.23 MPa, 4.23 MPa, 4.28 MPa and 4.30 MPa before blending, those values were not seen on figures obtained for any one of the four blends. Therefore, tensile strength property relevant to these four blends lied in the ranges of (4.46-10.13) MPa, (5.24-8.11) MPa, (5.69-13.82) MPa and (4.93-9.32)

MPa. Even though R_2, R_3 and R_5 had values for elongation at break above 150.94 % and below 67.88 %, results for elongation at break of all four blends varied between 67.88 % and 150.94 %. Therefore the elongation at break of four blends varied within (75.43-150.94) %, (67.88-132.56) %, (85.74-150.32) % and (92.71-132.43) %. Moisture content of almost all samples of R_2, R_3 and R_5 were below 2 % except 2.08 % of one sample of R_3. Neither the sample in four blends did not show a figure for moisture content above 2 %. Therefore it was evident from the figures in Tables (3.9-4.2) that ranges of specific gravity, elongation at break and moisture content of all blends (No: 6-No: 9) were quite comparable with the range of that parameter given in Table 4.5. Ranges of tensile strength of blend No: 6, blend No: 7 and blend No: 9, except that of blend No: 8 were also matched with the given specification. However, ranges of hardness obtained for blend No: 7, blend No: 8 and blend No: 9 have slightly deviated from the given specification. When frequency of occurring such deviations were less, effects of these deviation on the final product could expected to be minor. For an example, only one sample tested out of six samples of blend No: 8 showed a deviated result for tensile strength such as 13.82. In the same way, figure of hardness for only one sample in blend No: 7 and blend No: 8 have deviated from the accepted range. But majority of samples tested for hardness in blend No: 9 showed deviated results. Therefore it could be clearly seen that ranges of all properties obtained for blend No: 6 were quite matched with figures in Table4.8. In addition blend No: 7, blend No: 8 can also be accepted when minor deviations of hardness values are neglected.

Table 4.3
Properties of blend No: 10

Sample No	SG	HD	TS	EAB	Moisture content
	g/cm^3	IRHD	MPa	%	wt. %
S_1	1.17	94	5.56	68.67	0.95
S_2	1.16	84	6.20	68.40	1.01
S_3	1.17	85	3.88	138.23	1.48
S_4	1.17	85	7.00	72.27	1.23
S_5	1.17	90	6.51	69.47	1.56
S_6	1.17	91	5.88	86.53	1.39
Average	1.17	88	5.84	83.93	1.27

Table 4.3 shows the results of specific gravity, hardness, tensile strength, elongation at break and moisture content of blend No: 10. Blend No: 10 was different from blend No: 1 that sample from R_8 material has been blended with samples of both R_2 and R_3 in preparing blend No: 10, instead of R_5 used in blend No: 1. Having the average specific gravity of 1.19 gcm^{-3} which was higher than that of R_5, R_2 and R_3, addition of R_8 in blend No: 10 showed the average specific gravity of 1.17 gcm^{-3} which was higher than that of blend No: 1. Average hardness of R_8 was 93 IRHD which was slightly higher than that of R_5. Combination of R_8 with R_2 and R_3 has increased the average hardness of 85 IRHD in blend No: 1 up to 88 IRHD in blend No: 10. Even though R_8 had the average tensile strength of 5.52 MPa which was slightly lower than that of R_5 which was recorded as 5.86 MPa, average tensile strength has increased from 4.19 MPa in blend No: 1 to 5.84 MPa in blend No: 10. Average elongation at break of R_8 was 90.63 % which was lower than that of R_5. Average elongation at break of 133.23 % of blend No: 1 has decreased up to 83.93 % in blend No: 10 with the addition of R_8 sample. In addition, average moisture content of R_8 was 1.50 % which was greater than that of R_5. Then average moisture content has increased from 1.05 % in blend No: 1 to 1.27 % in blend No: 10.

According to the figures given in Table 4.3, figures for specific gravity which were lower than 1.16 gcm^{-3} such as 1.12 gcm^{-3} of R_3, 1.14 gcm^{-3} of both R_2 and R_3 and 1.15 gcm^{-3} of R_2 and figures for specific gravity which were higher than 1.17 gcm^{-3} such as 1.19 gcm^{-3}, 1.18 gcm^{-3}, 1.20 gcm^{-3} of R_8 could not be obtained for blend No: 10. Therefore, limits between which the specific gravity of blend No: 10 varied was (1.16-1.17) gcm^{-3}. In the case of hardness, 100 IRHD of both R_2 and R_8, 72 IRHD, 74 IRHD, 76 IRHD and 79 IRHD of R_3 were not obtained with results of blend No: 10. Consequently, hardness of blend No: 10 varied from 84 IRHD to 94 IRHD. In addition, values for tensile strength above 7 MPa such as 8.81 MPa, 14.43 MPa, 15.95 MPa, 16.72 MPa and 19.65 MPa of R_2 were not resulted for blend No: 10. Hence (3.88-7.00) MPa was the range in which test results of tensile strength of blend No: 10 lied. Furthermore, figures for elongation at break of the lied in the range of (68.40-138.23) % and hence results above 138.23 % and results

below 68.40 % of R_2 and R_3 were not obtained. No results above 2 % for moisture content was obtained and as a result, moisture content of the blend lied in the range of (0.95-1.56) %. In comparison with the specifications given in Table 4.8, range of specific gravity of blend No: 10 was quite matched. Only two figures of hardness out of six samples tested were slightly deviated from the accepted range. 3.88 MPa was approximate to 4 MPa and thus tensile strength can also be accepted. Elongation at break and moisture content also lied within the required range. Therefore range of almost all properties of blend No: 10 were quite matched with the specifications given.

Test results of specific gravity, hardness, tensile strength, elongation at break and moisture content of blends (No: 11-No: 14) are given in Tables (4.4-4.7).

Table 4.4
Properties of blend No: 11

Sample No	SG	HD	TS	EAB	Moisture content
	g/cm^3	IRHD	MPa	%	wt. %
S_1	1.14	77	8.93	77.47	0.99
S_2	1.14	86	10.9	48.88	0.93
S_3	1.14	75	9.49	76.13	1.21
S_4	1.14	84	5.69	128.27	0.74
S_5	1.14	83	8.84	83.27	0.89
S_6	1.14	84	9.65	67.87	1.14
Average	1.14	82	8.92	80.31	0.98

Table 4.5
Properties of blend No: 12

Sample No	SG	HD	TS	EAB	Moisture content
	g/cm^3	IRHD	MPa	%	wt. %
S_1	1.15	87	5.31	101.6	0.85
S_2	1.15	90	14.67	59.60	0.81
S_3	1.15	86	10.93	63.73	1.05
S_4	1.15	85	13.49	67.73	0.93
S_5	1.15	86	7.16	131.43	1.01
S_6	1.15	86	6.42	122.93	0.98
Average	1.15	87	9.66	91.17	0.94

Table 4.6
Properties of blend No: 13

Sample No	SG	HD	TS	EAB	Moisture content
	g/cm^3	IRHD	MPa	%	wt. %
S_1	1.14	86	8.66	72.8	0.97
S_2	1.14	87	11.04	66.8	1.11
S_3	1.15	85	5.60	134.2	0.95
S_4	1.14	91	5.85	125.07	0.97
S_5	1.15	86	11.46	63.87	1.08
S_6	1.14	83	9.14	60.4	1.17
Average	1.14	86	8.63	87.19	1.04

Table 4.7
Properties of blend No: 14

Sample No	SG	HD	TS	EAB	Moisture content
	g/cm^3	IRHD	MPa	%	wt. %
S_1	1.14	94	9.06	70.13	1.12
S_2	1.14	82	3.79	165.33	1.00
S_3	1.14	79	4.24	180.57	1.11
S_4	1.14	86	5.07	153.17	0.91
S_5	1.14	88	5.87	108.57	0.9
S_6	1.14	81	5.54	122.9	1.22
Average	1.14	85	5.60	133.45	1.04

1.14 gcm^{-3} was the lowest value for specific gravity among four blends including blend No: 11, blend No: 12, blend No: 13 and blend No: 14 whereas the highest value among them was 1.15 gcm^{-3}. Therefore specific gravities of R_7 sample such as 1.11gcm^{-3}, 1.12 gcm^{-3} and 1.13 gcm^{-3} have disappeared from the final four blends. In addition, no variation in specific gravity could be seen with blend No: 11, blend No: 12 and blend No: 14 and their average specific gravities are recorded as 1.14 gcm^{-3}, 1.15 gcm^{-3} and 1.14 gcm^{-3} respectively.

Average specific gravities of R_1, R_4 and R_7 were 1.14 $gcm^{-3,}$ 1.15 gcm^{-3} and 1.13 gcm^{-3} respectively. When they were mixed in 1:1:1 ratio to prepare blend No: 11, average specific gravity of the blend was 1.14 gcm^{-3}. Average specific gravity of blend No: 12 in where R_1, R_4 and R_7 were mixed in 2:1:1 ratio was 1.15 gcm^{-3}. Even though R_4 sample had the average specific gravity of 1.15 gcm^{-3} which was higher than that of both R_1 and R_7, average specific gravity of blend No: 13 in where weight fraction of R_4 was doubled, was 1.14 gcm^{-3}. Weight fraction of R_7 sample used in blend No: 14 was doubled. Even though R_7 had the lowest specific gravity of 1.13 gcm^{-3}, average specific gravity of blend No: 14 was as same as that of blend No: 11 and blend No: 13. Therefore, a significant variation on average specific gravities of blends (No: 11-No: 14) could not be seen with doubled weight fraction of R_1, R_4 and R_7 respectively. Figure 4.9 shows the variation in average specific gravity with relevant blend number.

Figure 4.9 Average specific gravity of blends with blend number

Average hardness values of R_1, R_4 and R_7 were 91 IRHD, 91 IRHD and 77 IRHD respectively. R_1, R_4 and R_7 were mixed in 1:1:1 ratio to prepare blend No: 11, its average hardness was 82 IRHD. Weight fraction of R_1, R_4 and R_7 used was doubled in blend No: 12, blend No: 13 and blend No: 14.Average hardness of

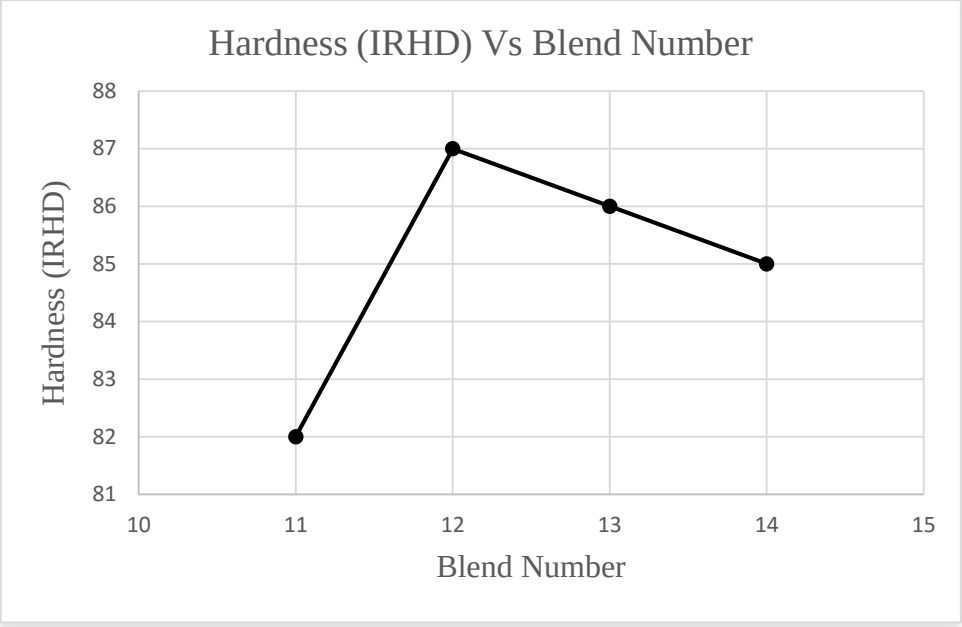


Figure 5.0 Average hardness of blends with blend number

82 IRHD of blend No: 11 was increased up to 87 IRHD in blend No: 12 where the weight fraction of R_1 sample used was twice the weight fraction of both R_4 and R_7. Average hardness of 87 IRHD was gradually decreased up to 85 IRHD which was the average hardness of blend No: 14 (Figure 5.0). Further it was evident that average hardness of the blend decreased with the increase weight fraction of sample having low average hardness value.

Average tensile strength of R_1, R_4 and R_7 samples were 11.62 MPa, 7.84 MPa and 4.84 MPa respectively. But the average tensile strength of blend No: 11 was 8.92 MPa (Table 4.4). That value was increased up to 9.66 MPa with the doubled weight fraction of R_1 and then there was a decreasing trend in average tensile strength in both blend No: 13 and blend No 14 with the addition of doubled weight fractions of R_4 and R_7 having low average tensile strength values like 7.84 MPa and 4.84 MPa respectively (Figure 5.1).

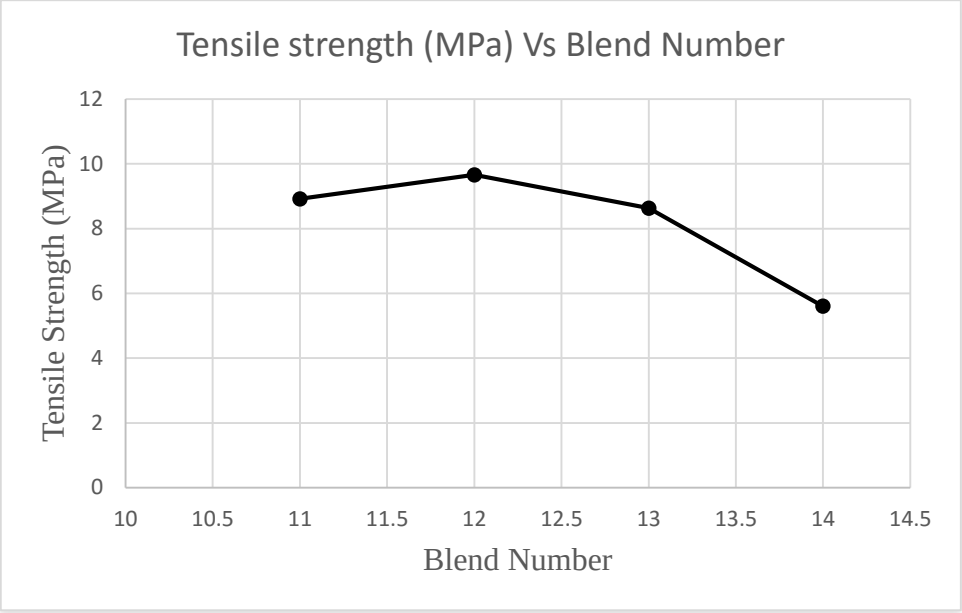


Figure 5.1 Average tensile strength of blends with blend number

Average elongation at break of R_1, R_4 and R_7 were 80.72 %, 122.96 % and 107.44 % respectively and that of blend No: 11 was 80.31 %. As in the case of hardness and tensile strength, it was expected to increase the average elongation at break of the blend with the addition of doubled weight fraction of samples having high elongation at break values. However such a correlation could not be observed in blend No: 13 with the addition of R_4, twice the weight of both R_1 and R_7, even though R_4 had the highest average elongation at break value (Figure 5.2).

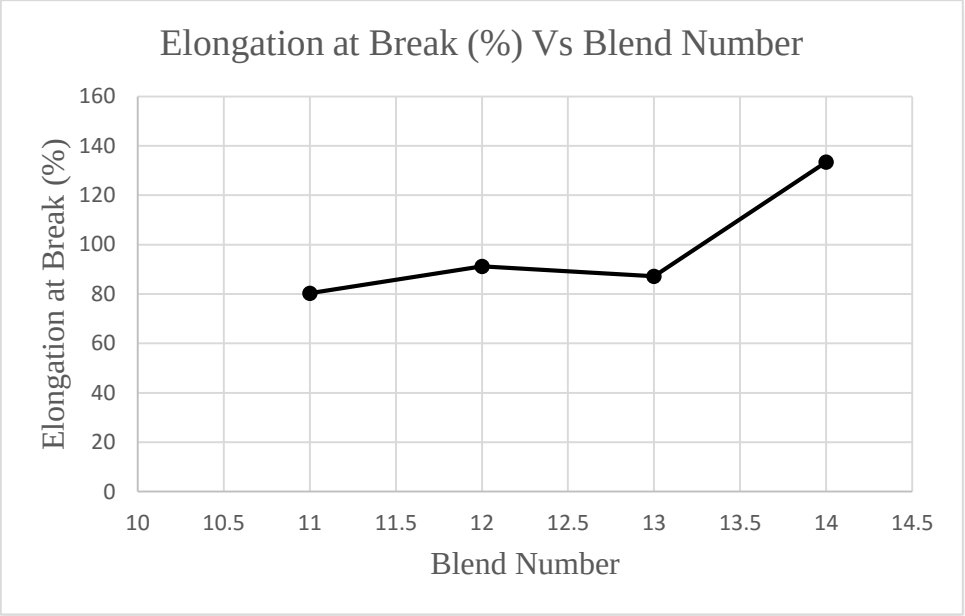


Figure 5.2 Average elongation at break of blends with blend number

Further, average moisture content of R_1, R_4 and R_7 were 0.91 %, 1.07 % and 1.12 % and 0.98 % was the average moisture content of blend No: 11 in where R_1, R_4 and R_7 had mixed in 1:1:1 ratio. When R_1, R_4 and R_7 were mixed in 2:1:1 ratio to prepare blend No: 12, its average moisture content got decreased up to 0.94 %. R_4 and R_7 having highest moisture contents like 1.07 % and 1.12 %, their addition in doubled weight fraction to blend No: 13 and blend No:14 respectively had increased the average moisture content up to 1.04 % which was thereafter remained constant (Figure 5.3).

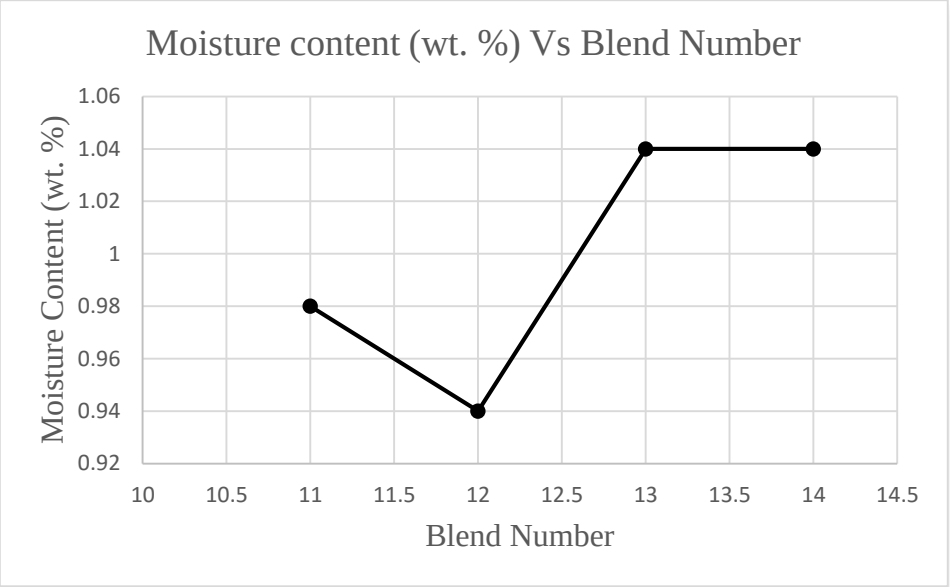


Figure 5.3 Average moisture content of blends with blend number

Table 4.8
Specifications of FRC-1 for solid tire base layer

Parameter	Unit	Specifications
Specific gravity	g/cm^3	1.17 ± 0.02
Hardness	IRHD	85 ± 5
Tensile strength	MPa	7 ± 3
Elongation at break	%	> 50
Moisture content	%	2 max
Cord length	mm	25

Table 3.1 showed that material, R_7 had values for specific gravity such as 1.11 gcm^{-3}, 1.12 gcm^{-3} and 1.13 gcm^{-3} prior to blending. But once the blends (No: 11-No: 14) were prepared, any one of these values were not resulted. Specific gravity of blend No: 11 and blend No: 14 was remained constant at 1.14 gcm^{-3} while it was remained constant at 1.15 gcm^{-3} for blend No: 12. In contrast specific gravity of blend No: 13 was lied within (1.14-1.15) gcm^{-3}. 73 IRHD of R_7 was the lowest among the values of hardness of R_1, R_4 and R_7. But hardness values below 75 IRHD were not obtained as the results of these four blends. While 93 IRHD was the highest among the values

of hardness of R_1, R_4 and R_7. But slightly deviated result from 93 IRHD such as 94 IRHD was obtained with blend No: 14. Therefore hardness of blend No: 11, blend No: 12, blend No: 13 and blend No: 14 were lied within the ranges of (75-84) IRHD, (85-90) IRHD, (83-91) IRHD and (79-94) IRHD respectively. Even though 13.46 MPa was the highest among values of tensile strength of R_1, R_4 and R_7 prior to blending result higher than that was obtained with blend No: 12. Then ranges for tensile strength of all four blends were between (5.69-10.90) MPa, (5.31-14.67) MPa, (5.60-11.46) MPa and (3.79-9.06) MPa respectively. 61.73 % was the lowest and 164.67 % was the highest among the results of elongation at break of R_1, R_4 and R_7. However, values lower than 61.73% such as 48.88 % and 59.60 % and values higher than 164.67 % such as 180.57 % were observed with the results of blend No: 11, blend No: 12 and blend No: 14 respectively. 0.74 % of blend No: 11 was the only value, lower than 0.80 % which was the lowest among values of moisture content of R_1, R_4 and R_7. Therefore, (0.74-1.21) %, (0.81-1.05) %, (0.95-1.17) % and (0.90-1.22) % was the range in which moisture content of blends (No: 11-No: 14) lied. According to these results, only the range of specific gravity of blend No: 12 was comparable with the range given in Table 4.5. In addition to specific gravity, hardness, elongation at break and moisture content of blend No: 12 was also matched with the specifications. Only two values of tensile strength out of six samples tested such as 13.49 MPa and 14.6 MPa were higher than that given in specifications. Therefore, almost all properties of blend No: 12, compared to that of blend No: 11, blend No: 13 and blend No: 14 were matched with figures given in Table 4.5.

5.3 Effects of Friction Cord on Properties of Rubber Compound

Rheometer test results are given in Table 4.9. It can be seen from the obtained values of minimum torques, that replacing the nylon flocks with friction cord resulted in reduction of viscosity of green compounds. Lower minimum torque makes it easier to process green compound and requires less power for example for

warming up, cutting, shaping. Shear modules characterized by maximum torque was the measure of cured compound stiffness favored to friction cord filled compounds. Scorch time was reduced with increasing the friction cord quantity, as it might already include curing group that contributed to vulcanization of rubber compounds to which friction was added. Optimum cure time (t_{c90}), which was the time required for the torque to reach 90 % of the maximum achievable torque (T_{90}) and related to the time necessary for the cured rubber to achieve optimal properties was definitely shorter for friction cord filled compound, due to the above described reason.

Table 4.9
Rheological characteristics of compounds filled with friction cord

Compound No	1	2	3	4	5	6
Nylon flocks-friction cord content	100-0	80-20	60-40	40-60	20-80	0-100
Minimum Torque (kg/cm)	0.85	0.78	0.74	0.72	0.70	0.68
Maximum Torque (kg/cm)	13.8	16.88	18.3	22	24	28
Scorch Time t_{10} (min)	3.9	3.6	3.45	2.9	2.9	2.5
Cure Time t_{90}(min)	9.5	9.1	9	8.37	8.20	8.0

Physical and Mechanical properties of samples made of prepared rubber compounds were determined and displayed in the Tables 5.0. It was evident that specific gravity of compounds was at the same level, as specific gravity of both fiber fillers nylon flocks and friction cord was the same in the range of 0.998-1.011 g/cm^3.The strength characteristics were benefited by addition of friction cord. This could be explain, that friction cord composition included partially cured rubber. That rubber was capable to form three-dimensional network of chemicals bonds with rubber present in compounds to where friction cord was added. These chemical bonds were formed during vulcanization process. While nylon flocks were free of rubber polymer and they were capable of participating in physical interaction only

with rubber chains. Hardness level was also higher for friction cord filled compounds as there was contribution to cross-links density. Elongation at break was at the same level for all compounds, may be a little higher for compounds with prevailing quantity of nylon flocks.

Table 5.0
Properties of rubber compounds

Rubber compounds No	1	2	3	4	5	6
Specific gravity, g/cm3	1.06	1.09	1.1	1.1	1.1	1.05
Hardness,Shore A	68	75	76	79	80	85
100% Modulus MPa	3.50	3.6	3.8	4.0	4.2	4.5
Tensile strength, MPa	11	12.5	12.5	13.5	13.5	14.0
Elongation at break,%	290	250	200	180	205	200

6. CONCLUSION

1. According to the test results mentioned, almost all the data ranges for physical properties including specific gravity, hardness, tensile strength, elongation at break and moisture content of blend No: 1, blend No: 6, blend No: 10 and blend No: 12 were quite comparable with that of the specifications of friction cords available at market for use in rubber compounds

2. Moreover, frequency of occurring of deviated results from the accepted range was minor in blend Nos: 2, 3, 4, 5, 7 and 8. Therefore the ranges of those blends were also accepted.

3. Scattered data obtained for individual materials such as R_1, R_4 and R_7 prior to blending have come closer after blend No: 11, blend No: 13 and blend No: 14 were prepared. That means all the properties can be controlled within a particular range.

4. In comparison the results of each blends, it was evident that materials having higher results for parameters should be mixed together with that having lower results for parameters gave better properties. Therefore it can be come to the conclusion that friction cords can be standardized by physically mixing friction cords in different weight proportions.

5. It was evident from the results of experiment that almost all the properties except the specific gravity of R_4, got varied within the same bulky material (rubberized nylon friction). Therefore the variation in each and every property was the common feature found in friction cord.

6. Replacement of nylon flocks in prepared rubber compounds with friction cords have made an influence on the vulcanization process and on formation of cross links in the rubber compounds by reducing the lower minimum torque, scorch time (t_{10}) and optimum cure time (t_{c90}).

7. Maximum torque got increased with the increased quantity of friction cord and as a result of this hardness property also increased. Addition of friction cords also led to the increase in tensile properties, and modulus at 100 % elongation whereas the specific gravity and elongation at break of compounds remained at same level for all prepared compounds.

REFERENCES LIST

[1] Fang, Y., Zhan, M., Wang, Y. (2001). The status of recycling of waste rubber. Materials and Design, 22(2), 123-127.

[2] Ramarad, S., Khalid, M., Ratnam, C.T., Luqman Chuah, A., Rashmi, W. (2015).Waste tire rubber in polymer blends: A review on the evolution, properties and future. Progress in Materials Science, 72, 100-140.

[3] NIIR Board of Consultants and Engineers.(2010).The Complete Book on Rubber Processing and Compounding Technology. Delhi:Asia specific Pacific Business Press Inc.

[4] Jayalatha, G. and Kutty, S.K.N. (2013). Effects of short nylon-6 fibers on natural rubber-toughened polystyrene. Materials and Design, 43, 291-298.

[5] Mortazavian, S. and Fatemi, A. (2015).Effects of fiber orientation and anisotropy on tensile strength and elastic modulus of short fiber reinforced polymer composites. Composites. Part B 72,116-129.

[6] Unterweger, C., Bruggemann, O. and Furst, C. (2014). Effects of different fibers on the properties of short-fiber-reinforced polypropylene composites. Composites Science and Technology. 103, 49-55.

[7] McDonel, E.T.(2006). Tire cord and cord-to-rubber bonding. In A.N. Gent & J.D. Walter(Eds.), Pneumatic tire (pp 80-104). Ohio, OH: Department of Mechanical Engineering: The University of Akron.

[8] Clark, S.K.(Ed.). (1981). Mechanics of Pneumatic Tires. Washington, D.C:U.S. Department of Commerce.

[9]Tadmor, Z. and Gogos, C.G. (2006). Principles of polymer processing. New Jersey, NJ: John Wiley & Sons.

[10] Abraham, E., Cherian, B.M., Pothen, L.A., Thomas, S. (2011).Recent advances in the recycling of rubber waste. Recent Developments in Polymer Recycling. 47-100

[11] Yung, W.H.,Yung, L.C. and Hua, L.H.(2013). A study of the durability properties of waste tire rubber applied to self-compacting concrete. Progress in Materials Science.72, 100-140.

[12] Fukumori, K., Matsushita, M., Okamoto, H., Sato, N., Suzuki, Y., Takeuchi, K. (2002) Recycling technology of tire rubber. JSAE Review. 23(2), 259-264

[13] Adhikari, B., De, D., Maiti, S. (2000).Reclamation and recycling of waste rubber. Prog. Polym. Sci. 25(7), 909-948.

[14] Fiksel, J,, Bakshi, B.R., Baral, A., Guerra, E., Quervain, B.D. (2011).Comparative life cycle assessment of beneficial applications for scrap tires. Clean Techn Environ Policy.13,1 9-35.

[15] Global and China Tire Industry Report, 2016-2020. (2017, January 19). Retrieved from http://www.energyreturnwheel.com/News/Global-and-China-Tire-Industry-Report,-2016-2020.aspx

[16] Amari,T., Themelis, N.J. and Wernick, I.K.(1999). Resource recovery from used rubber tires. Resources Policy.25, 179-188.

[17]Martin, J.M. and Smith, W.K.(2004).Handbook of rubber technology: natural and synthetic rubber and technology of vulcanisation vol 1.New Delhi, DL: CBS Publishers and Distributors.

[18] King, S.M. and Bucknall, D.G. (2005).Microstructural characterization of surfactant treated nylon fibers. Polymer. 46(25), 11424-11434.

[19] Tanner,D., Fitzgerald, J.A. & Riewald, P.G. (1989). Aramid structure/property relationships and their role in applications development. InM.Lewin, &J.Preston, (Eds), Handbook of fiber science and technology vol.III Part B.(pp.35-55).New York, NY: Marcel Dekker INC.

[20] Rachchh, N.V.,Ujeniya, P.S. and Misra, R.K. (2005).Mechanical characterisation of rattan fibre polyester composite. Procedia Materials Science. 46(25), 1396-1404.

[21] DE, S.K. and White, J.R. (Eds). (1996). Shortfiber-polymer composites. Cambridge, CB: Woodhead Publishing State.

[22] Geethamma, V.G., Kalaprasad, G.,Groeninckx, G.and Thomas, S.(2005). Dynamic mechanical behavior of short coir fiber reinforced natural rubber composites. Composites: Part A. 36(11), 1499-1506.

[23] Ou, R., Zhao, H., Sui, S., Song, Y. and Wang, Q. (2010). Reinforcing effects of Kevlar fiber on the mechanical properties of wood-flour/high-density-polyethylene composites. Composites. Part A 41, 1272-1278.

[24] Wake, W.C. and Wootton, D.B.(1982). Textile reinforcement of elastomers. London and New Jersey, LDN and NJ: Applied Science Publishers Ltd.

[25] Hu, G.,Wang, B. and Gao, F. (2006).Investigation on the rheological behavior of nylon 6/11.Materials Science and Engineering A.426(1-2),263-265.

[26] Deepalekshmi, P., Visakh, P.M., Mathew, A.P., Chandra, A.K. & Thomas, S.(2013). Advances in elastomers: their blends and interpenetrating networks-state of art,new challenges and opportunities. In P.M. Visakh., S.Thomas., A.K. Chandra, &A.P. Mathew (Eds),Advances of elastomers I (pp.1-9).New York,NY: Springer-Verlag Berlin Heidelberg.

[27] Karsli, N.G. and Aytac, A.(2013).Tensile and thermomechanical properties of short carbon fiber reinforced polyamide 6 composites. Composites: Part B. 51, 270-275.

[28] Meissner, N. and Rzymski, W.M. (2013). Use of short fibers as a filler in rubber compounds. AUTEX Research Journal. 13(2), 40-43.

[29] Unterweger, C., Bruggemann, O. and Furst, C. (2014). Effects of different fibers on the properties of short-fiber-reinforced polypropylene composites. Composites Science and Technology. 103, 49-55.

[30] Kikuchi, N. (1998). Composition for tread rubber of tires, U.S. Patent 5852097.

[31] Lucas, D., Agostini, G., Corvasce, F.G., Hunt, J.O. and Louis, O. (1999). Tire tread for ice traction, U.S. Patent 5967211

[32] Causa, A.G., Obermaier, C.H. and Borowczak, M. (1996). Elastomers containing partially oriented reinforcing fibers, tires made using said elastomers, and a method therefor, U.S. Patent 5576104.

[33] Nakamura, E. and Ishikuro, T. (2002). Rubber composition for tires and pneumatic tire, U.S. Patent 6472461.

[34] Mizuno, Y., Komatsuki, M. and Tsumori, I. (2001). Vehicle tire including conductive rubber. U.S. Patent 6302173.

[35] Brown, R.J. and Scriver, R.M. (1989). Rubber containing aramid pulp reinforcement. U.S. Patent 4871004.

[36] Borowczak, M., Burlett, D.J., Bauer, R.G. and Miller, J.W. (1993). Reinforced polymer matrix and product containing micro and macro reinforcement. U.S. Patent 5225457.

[37]ASTM D 792-08 standard test methods for density and specific gravity (relative density) of plastics by displacement. ASTM book of standards volume: 09.02.

[38] Wood, L.A., Bekkedahi, N. and Roth, F.L. (1943). Density measurements on synthetic rubbers. Rubber Chemistry and Technology, 16(1), 244-248. Retrieved from https://doi.org/10.5254/1.3540104