Chapter 1

Introduction and Literature Review

In the present research work, an attempt has been made to identify an eco-friendly natural fiber to be used as reinforcement in the manufacture of brake friction material. There is an increase in the environmental awareness in the world which has aroused an interest in the research and the development of biodegradable and high performance materials. The first generation of modern brake materials was asbestos fiber reinforced composites. Due to the environmental problem the natural fibers were introduced instead of asbestos fiber in this research work. The thermal, mechanical and tribological properties of various natural fibers were studied and analyzed. Specimens for study were prepared by compression moulding technique through a diffusion bonding machine. Then the prepared specimens were subjected to Thermal Gravimetric Analysis (TGA) and Differential Scanning Calorimetric Analysis (DSC) to study the thermal properties. Wear tests were conducted on a pin-on-disc tester to study the wear properties. The worn specimens were then put under a Scanning Electron Microscope for detailed analysis of the severity of wear. Fuzzy Clustering Algorithm was used for the generation of wear maps. An introduction to the Polymer matrix composites, their manufacturing, testing of various properties and analysis methods in the present study is presented below in this section.

1.1. Brake Friction Materials

Brake pads are primarily used to slow down a vehicle by converting kinetic energy into heat through friction that takes place at the interface between brake pad and a rotor disc. The brake pad is almost always the reason for brake failures. This is
because, the brake pad is the component that is at the receiving end when a brake is applied and is subjected to wear and tear depending upon pedal pressure, vehicle speed, disc temperature, and environmental conditions. The problems created are unwanted vibrations due to rotor warping (judder), decreased brake effectiveness (fade) and some noise [1]. A stable friction coefficient at any condition, irrespective of temperature, humidity, age, amount of wear and corrosion, dirt and water must be maintained by the brake pad material. Added to this, it must also meet all safety requirements, have a long life, and provide high comfort, with absence of vibration and noise. The variation in friction coefficients are influenced by the ingredients of brake pad materials and braking conditions. About 10-15% of the rubbing surface of a rotor disc is covered by brake pads. The pad is pressed against the disc with an estimated force of about 5 kN, when the brake is applied slightly (assuming typical pad size of 80mmx50mm) producing a nominal contact pressure of about 1.2MPa at the pad surface. However when the brake is applied hard, the surface pressure could touch 10MPa [2]. Also, a high surface temperature approximately 200°C to 400°C is produced while braking along with pressure. This pressure and temperature have to be taken into account while choosing frictional material for brake pads. While rotor discs are commonly made from cast iron, metallic fibers or asbestos is used with appropriate binder resin for brake pads. Usually, Phenolic resin is used as a binder for fabricating brake pad materials and further added with mineral fibers, fillers, friction modifiers, abrasives and metallic particles that modify characteristics of heat flow. The type and amount of ingredients are determined on the basis of empirical observations [3]. Although binder resins are commonly blamed for shortcomings in braking and subsequent problems, right fiber reinforcements are the solution for improving physical strength and friction performance [4].
Brake friction materials usually contain the following ingredients of a binder, reinforcement, friction modifiers, fillers and solid lubricants. Nicholson et al., have asserted that the volume percentage is the correct unit of measure for brake friction material composition [5]. The exact compositions of commercial brake friction materials are almost never published in an open literature. Commercially available automotive brake pads are roughly categorized as semi-metallic (SM), low-metallic (LM), or non-asbestos organic (NAO) materials. They are all considered to be organic friction materials since the matrix of these complex composites is formed by one or more polymers [6]. According to the regulations against hazardous ingredients, several raw materials usually used in commercial friction materials could have a potential negative environmental impact. Components such as antimony trisulfide, copper, lead, tin, potassium titanate whisker, silicon carbide whisker, and others are often discussed [7].

Keskin studied the effect of zeolite content on the friction and wear behavior of brake pad used in automotive industry. A highest friction coefficient and lowest wear rate was obtained for 10% zeolite containing specimen. The author (Keskin) concluded that zeolite was compatible with other constituents and efficiently used in brake pad formulation [8].

Zhu et al., have studied the potassium titanate, magnesium borate and calcium sulfate whisker modified non-metallic friction materials prepared by compression moulding process. The results showed that the mechanical and thermal properties were increased by addition of whiskers. Among three types of whisker, potassium titanate whisker showed the best improvement in wear-resistance, and calcium sulfate whisker increased the friction coefficient and stability mostly at higher sliding speeds.
Specifically, Magnesium borate exhibited higher tensile strength and Calcium sulfate showed the best thermal stability and increased coefficient of friction at high sliding speeds [9].

Mathuretal., have asserted that carbon fibers as reinforcement and graphite powder as friction modifier are two potential carbon materials which are useful in the formation of asbestos free brake pad materials. Hardness of materials played a vital role and further it can be controlled by suitable modifications in the composition of the composite material for tribological applications. Hardness could be reduced by using graphite powder as friction modifier without affecting flexural properties [10].

Fan et al., have studied that the tribological properties of the semi-metallic friction materials reinforced with Al₂O₃. The addition of the abrasive Al₂O₃ powder leads to a higher friction coefficient. The composite with 5.6% V_f of Al₂O₃ have the most suitable friction wear properties that can be used for car brake lining manufacturing [11].

1.2. Polymer Matrix Composites

Composite materials are composed of at least two different materials working together exhibiting properties that are quite different from their individual properties. Composites are different from alloys in the way that they are combined in such a way that it is impossible to tell one particle, element, or substance from the other. Composites have two (or more) chemically distinct phases on a microscopic scale, separated by a distinct interface, and it is important to be able to specify these constituents. The constituent that is continuous but not always present in the greater quantity in the composites is the matrix. Some composite materials also occur in
nature. Wood is a natural composite consisting of cellulose as the fiber and lignin as the matrix. Polymer composites are lighter in weight and are having better heat and corrosion resistance than conventional plastics or natural composites. They were first developed in the 1940s for military and aerospace applications. Today, most composites consist of at least one bulk material called the 'matrix', combined with a fibrous reinforcing dispersed phase. Use of non-reinforced polymers as structure materials is limited by low level of their mechanical properties. Properties of Polymer Matrix Composites are determined by the Wt% or vol% of the concentration of the fibers and the properties of the matrix. In addition to relatively low strength, polymer materials possess low impact resistance. The reinforcements that are usually in fiber form are added primarily to increase the strength and stiffness of the matrix. The composite, in which the bulk material or matrix is based on polymers, is called Polymer Matrix Composite (PMC). The other types of composites classified based on the matrix are Metal Matrix Composites (MMC) and Ceramic Matrix Composites (CMC). In general, polymers have low strengths and Young’s modulus, ceramics are strong, stiff and brittle, and metals have intermediate strengths and modulus together with good ductility.

Polymer Matrix Composites have several advantages. They have better strength and stiffness compared to monolithic polymers. Fabrication of Polymer Matrix Composites (PMC) are characterized by high tensile strength, high stiffness, good abrasion resistance, good puncture resistance and good creep resistance making them suitable for a variety of applications. PMCs also exhibit high thermal expansion, elastic modulus and ductility levels compared to their metal and ceramic counterparts. Unlike metallic matrices, polymers are also immune to corrosion. On the other hand, PMCs also have certain limitations. In comparison to other matrix polymers, PMCs
have lower temperature strength. Polymer Matrix Composites are very popular due to their low cost and simple fabrication methods and have applications in the aerospace, automotive and marine industries [12]. The design freedom of PMCs (especially thermoplastics) to draw ribs or to locally increase the wall thickness of plastic parts and the ability to integrate functions which reduces the number of parts are notable advantages. Added to this, the collateral properties of plastics namely insulation, transparency, aesthetics, corrosion resistance and the ease of combination with other materials such as metals, textile, and others make PMCs an attractive replacement to metal alloys. PMCs are used for manufacturing automotive parts, secondary load-bearing aerospace structures, boat bodies, canoes, kayaks, radio controlled vehicles, golf clubs, skis, tennis racquets, fishing rods, bullet-proof vests and other armor parts, brake and clutch linings. The exhibition of lower resistance to wear by PMCs makes them suitable for use in applications such as brake friction in automobiles. PMCs are used alongside steel and aluminum bodies in automobile industries. Shafts, spars and hulls for boats are also made from PMCs. Civilian and military aircraft components, rocket components and missile construction in aeronautics use PMCs. Use of PMCs in manufacturing breadboards for electronic circuits and communication antennae has spurred interest in their research in recent past. PMCs also find use in safety equipments such as ballistic protection and air bags in cars [13].

1.3. Phenolic Resin

Phenolic resin is probably the most common resin binder used in brake friction materials, since it is cheap to produce. The other materials that are used as binder for such applications include silicon modified phenolic resin, COPNA resin, cyanate ester resin, epoxy modified phenolic resin, thermoplastic polyimide resin. In this work the
Resole type Phenol formaldehyde where the mole ratio of phenol to formaldehyde is less than one. The role of matrix in a composite material is to bind the fibers together in an orderly array and protect them from the environment. The matrix transfers loads to the fibers, which is critical in compression loading by preventing premature failure due to fiber micro buckling. The matrix also provides the composite with toughness, damage tolerance, impact and abrasion resistance. The resins used in fiber reinforced plastics are otherwise called as polymers, which are composed of long chain like molecules. They are classified as thermoplastic and thermosetting resins according to the effect of heat on their properties. Thermoplastics, like metals, soften with heating and eventually melt, hardening again with cooling. This process of crossing the softening or melting point on the temperature scale can be repeated as often as desired without any appreciable effect on the material properties on either state. Numerous different thermosetting adhesives and resins are used industrially. Among these, thermosetting resins based on the use of formaldehyde base d resins obtained by poly condensation have dominated the field for many decades. Phenol-formaldehyde resins also the first thermosetting plastics, are considered to be the first synthetic commercially available plastic resins. Phenolic resins completely made of synthetic materials only were the first manmade plastic resins. However, nowadays natural polyphenolic materials based resins called condensed tannin resins are used in industrial applications. Phenol-formaldehyde resins are formed by the chemical reaction between phenols and formaldehyde solutions (formalin).

Phenolic resins are used in several applications such as insulation, friction binders, foundry sand binders, plywood and engineered lumber, open or closed cell foams, oriented strand boards, abrasive binders, high-pressure laminating resins and paper saturating resins. They are used to make several diverse products such as
fiberglass insulators, different grades of plywood and engineered lumber, abrasive coatings, hardboard, fiberboard, floral foam supports, and paper saturating resins for oil filters, overlay, paint roller tubes and petroleum recovery binders. Phenolic foam resins are cured and used to make open or closed cell foams. The applications for open cell foams with openings in cell walls include making floral foam supports such as those used for retaining flower stems in water. The open cell walls in the foam soak up water several times its original weight and provide water over sustained periods of time for the flowers. Other uses for phenolic foams are dense closed cell foams used for models to hold sophisticated firearms, jewelry, and in making moulds for prosthetics. In general, closed cell foams find use in barrier and insulation applications [14].

Bijwe et al., have concluded that there were no clear correlations between friction or wear and the thermal stability of the resins or the mechanical properties of the polymer matrix composites. The alkyl benzene modified resin composite proved as a best frictional performance which is more important than wear in brakes. The linseed oil modified phenolic resin which had the worst thermal stability, low strength and poor friction performance. The straight phenolic based composite proved better tribological properties than CSNL and nitrile NBR [15].

1.4. Natural Fiber Reinforced Polymer Composites

Many combinations exist and hence many composites can be formed. The most common composites used in manufacturing are composed of strong fibers held by a binder or matrix. Unlike conventional materials, properties of composites can be designed simultaneously with structural aspects. This gives rise to numerous possibilities to manipulate material properties by changing the fiber orientation, fiber
content and geometry. The important factors influencing mechanical properties of fiber reinforced composites include (i) direction of fibers, (ii) position of fibers, (iii) adhesion of fibers to the polymer matrix, (iv) quantity of fibers, (v) inherent material properties of fibers and polymer matrices and (vi) fiber surface treatment (sizing) and impregnation of fibers with resin. FRP composites form an important class of tribological materials that possess unique self-lubrication capabilities and low noise. With numerous possible material combinations, FRP composites provide nearly unlimited possibilities for optimizing tribological performance of constituent components. For this reason, FRP composites are widely utilized in numerous applications including seals, bearings, gears and artificial prosthetic joints [16]. Fiber Reinforced Composites that use natural fiber as reinforcements are generally termed Natural Fiber Reinforced Composites (NFRCs). Natural fibers have been used as reinforcements in composite materials for over 3,000 years. Examples of such use are reinforcing wood walls with bamboo sticks and reinforcing mud bricks with straw.

More recently, natural fibers are being used in combination with polymers and plastics. Many types of natural fibers are in use with plastics such as flax fiber, hemp fiber, jute fiber, straw fiber, wood fiber, rice husk fiber, wheat fiber, barley fiber, oats fiber, rye fiber, cane fiber (sugar and bamboo), grass reed fiber, kenaf fiber, sisal fiber, coir, banana fiber and papyrus. Natural fibers have a certain advantage over artificial fibers in that they are bio-degradable, thus being environment friendly and having a marketing appeal. In Asia, natural fibers can quite commonly be found in use such as usage of jute in Bangladesh and India in natural matrix composites used for domestic purposes. PMCs with natural fiber reinforcements have a wide variety of applications in packaging and automobile industries. The demand from these
industries for NFRCs is growing at a rapid pace with the environment protection laws getting stringent in order to avoid asbestos.

Unlike artificial fibers that require industrial production, natural fibers can be acquired at negligible costs in India. Agricultural wastes such as rice husk, wheat husk, straw, hemp, shells of dry fruits, banana etc., are some examples of natural fibers that are abundantly available in India that are relatively cheap but still possess commercial utility. Tested natural fibers can replace asbestos in reinforcing the friction composites, where their friction and wear properties were found to be much better than glass fibers. It is observed that friction coefficient decreased with increasing load and reinforcing composites with natural fibers causes significant decrease in friction coefficient compared to that reinforced by glass fibers [17].

Bajpai et al., concluded that the overall average friction coefficient of PLA polymer was not much affected after natural fiber reinforcement. However, the maximum value of the friction coefficient for the developed composites was reduced as compared to maximum value of friction coefficient for the neat PLA. Wear performance of PLA was significantly improved due to the addition of natural fibers as the specific wear rate of composites was considerably less as compared to specific wear rate of neat PLA, especially at higher loads. Debonding was significantly observed in SEM micrographs of composite specimens after sliding wear testing. The SEM images also showed ploughing in the resinous region confirming the presence of abrasive type of wear mechanism. The experimental work acknowledged that the natural fibers as an acceptable candidate for reinforcement in composites for tribological applications [18].
Thakur et al., have reported that the properties of natural fiber reinforced composites were strongly influenced by environmental conditions and superiority of natural fibers used as reinforcement. These results also indicate that the presence of Hibiscus sabdariffafibers have affected the thermal stability of the polymer matrix. The initial decomposition temperature (IDT) and final decomposition temperature (FDT) values for composites were found between those of matrix and fiber, which indicates that the composite is thermally a little bit less stable than the resin matrix and it can be used in automobile applications [19].

Thakur et al., have fabricated a low-cost, eco-friendly biodegradable composite materials from a waste biomass such as pine needles and a polymer matrix. They stated that pine needles have high potential ability to work as a reinforcing material in a polymer matrix. High weight content of pine needles enabled the polymer composites to increase their strength in the most effective way when the pine needles were incorporated into the polymer matrix. Further they declared that it can be used as an ideal substitute for synthetic fibers for synthesis of polymer bio composites and eco-friendly material [20].

Ramamoorthy et al., have reviewed about the use of natural fibers in composites due to their environmental and economic benefits. The market for natural fibers increase over the last decade and experts predict a continuation of this trend in the future. It also has unique properties such as low density and good strength. Natural fiber composites have found the commercial applications in automotive, aircraft, marine, and construction industries. Several composites have been produced from various plant and animal fibers while only few of these fibers have actually been used in industrial scale. The moisture absorption of the fiber and fiber-matrix has to
be addressed to improve the properties. Currently, the natural fiber reinforced composites are mostly used in indoor applications and its potential in outdoor applications can be enhanced [21].

Thakur et al., have reported that the natural fibers are one of the potentially low-cost, environmentally friendly materials that can be an indispensable component of polymer composite applications. Different kinds of natural fibers, due to their bio-renewable nature and inherent eco-friendly characteristics, offer a number of advantages over synthetic fibers such as glass fibers, aramid fibers, and carbon fibers [22].

Thakur et al., have studied the characteristics green composites were fabricated with grewiaoptiva fibers using phenolic resin as polymer matrix. The fiber was assessed in long fiber form to improve the mechanical properties through increasing fiber content. The effect of fiber loading on liquid absorption and chemical resistance was also investigated. The study also concluded that natural fiber reinforcement has a beneficial effect in the adhesion of the polymer resin into the green composites[23].

Faruka et al., have stated that interfacial adhesion between natural fibers and matrix is a major role to obtain the final properties of the composites. Addition to that various types of surface modifications, different types of matrices as well as fabrication methods decide the performance of composites. The study further reported that some of the obstacles such as moisture absorption, inadequate toughness, and reduced long-term stability for outdoor applications should be addressed [24].
Azwa et al., have concluded that the degradability of polymer composites based on natural fiber is due to moisture, thermal effects, and fire and ultraviolet rays. Natural fibers are susceptible to biodegradation thus composites based on them face higher risk of degradation when subjected to outdoor applications as compared to composites with synthetic fibers. Different cell wall polymers of lignocellulosics fibers have different influence on their properties and degradability. For instance, cellulose is responsible for strength of fibers, hemicelluloses for thermal, biological and moisture degradation, while lignin for UV degradation and char formation. Fiber content is the major factor affecting water absorption of composites as it enhances matrix porosity by creating more moisture path into the matrices. Poor adhesion between fiber particles and polymer matrix generates void spaces around the fiber particles. The study further inferred that the moisture absorption can be reduced through fiber modifications such as alkalization and addition of coupling agents [25].

Nirmal et al., have reviewed that the information on natural fibers, polymers and their composites on tribological performance. Types of adhesive wear mechanism incurred for the different types of composites and their performance on wear, friction, temperature, surface roughness, contact condition and test parameters have been highlighted. The study also professed that there are still many varieties of natural plants and natural fibers which have not been explored and if explored it would lead to new discoveries that would bring great development in related industries [26].

Mahmoud et al., have concluded that the friction coefficient decreased with increasing load and reinforcing the tested composites by the natural fibers caused significant increase in friction coefficient. The highest values of friction coefficient
were exhibited by composites reinforced by the fibers of 15 wt. % corn, 15 wt. % Nile roses, 10 wt. % straw, 5 wt. % wheat and 20 wt. % sunflower. Fibers of Nile roses exhibited the highest friction values compared to the other tested fibers. Minimum wear values were observed for composites reinforced by 10 wt. % wheat fibers [27].

Shalwan et al., have asserted that the volume fraction, physical properties and orientation of natural fiber have significant influence on the mechanical and the tribological performance of the composites. The nature of the fibers controls the mechanical and the tribological behaviour of the composites. Also they stated that there is no remarkable correlation between the mechanical and tribological performance of major polymeric composites. However, for natural fiber/polymer composites, treatment of the fibers has influenced both mechanical and tribological behaviours of the composites. Treating the natural fibers assist to stabilise the bonding area between the fiber and the matrix which enhanced the ability of the fiber to carry the load under mechanical and tribological loadings. Natural fiber polymeric composites suffer from high friction coefficient. It is suggested to use graphite as solid lubricant for such composites, which may reduce the friction coefficient of the composite and maintain high wear characteristics [28].

Satyanarayana et al., have avowed that the research on biodegradable polymer composites containing lignocellulosicfibers is generating increasing attention due to the decreasing petroleum resources, low cost of lignocellulosic reinforcements with a variety of properties and increasing ecological considerations. In general, the use of lignocellulosicfibers in biodegradable composites can help to generate jobs in both rural and urban areas, in addition to helping reduce waste, thus contributing to a healthier environment[29].
Kozlowski et al., have reported that global trends towards sustainable development have brought to light natural, renewable, biodegradable raw materials, among them bastfiber is one of the best. Recent achievements and new applications of green fibers and associated products of bast fibrous plants are creating large space for future expansion of other than cottons natural cellulosic fibers. Green fibrous plants provide valuable by-products like seeds, waxes, fragrances, and pigments. These may be used for food, fodder, pharmaceutics, cosmetics, and body-care items and industrial applications [30].

Xinet al., have concluded that the friction and wear properties of sisal brake composites up to the optimum point with the proportion between resin and sisal fibre is 3:4 and it has high friction factor and low wear rate. The sisal has the potential to be an ideal substitute fiber of asbestos for brake composites [31].

1.5. Properties of Flax and Basalt Fibers

Zhuet al., have asserted that the inherent detriments of flax, including moisture adsorption and incompatibility with some polymeric systems due to high hydrophilicity, present many challenges with respect to composite design and applications. They study further professed that various chemical treatments, such as mercerization, silane treatment and benzylation flax fibers can improve the interface between fibers and matrix.

Flax fiber composites have a wide range of properties, depending on the matrix type, such as thermoplastic, thermosets and biomaterials. Flax/PP composite is the most commonly studied composite and has been commercially used in automotive applications (e.g., vehicle panels). The humidity sensitivity is still a problem as it
decreases the long-term material properties. The properties of flax/epoxy composites are strongly influenced by the processing methods and fibre configurations. Resin transfer moulding and compression moulding are reported as effective manufacturing technique for production of high performance flax/epoxy composites[32].

Kalia et al., have reported that the graft copolymerization have improved the water repellency of flax fibers and also the study proclaimed that the reinforcement of the phenol-formaldehyde resin with flax-g-poly (MMA) improved the tensile strength as well as the compressive strength of the composites [33].

Manikandan et al. have investigated the performance of basalt fibre reinforced composites with unsaturated polyester and concluded that the composite was found to be superior then glass fibre reinforced composites. The tensile tests showed that acid-treated basalt fibre reinforced composite had higher tensile strength values than other combinations. The glass fibre composite was much more affected by the base treatment than the basalt fibre reinforced composites. The impact tests showed that the acid-treated basalt fibre reinforced composite had greater impact strength [34].

Dhand et al. have reported that the use of basalt fiber as a reinforcement for composites used for military operations involving the fabrication of strong and lightweight material for anti-ballistic applications and automobile and aerospace applications is being an increasing trend. Basalt was found to have superior properties than the conventional asbestos and glass fibers put together. Presently, basalt fibers are almost as favourable as carbon fibers, but have an edge as they are eco-friendly, non-toxic, and green. Further, basalt is chemically inert, highly resistant to corrosion, and possesses very low thermal conductivity making it superior to any other reinforcement available today. The study also reported that by hybridizing the
surface of basalt fibers with coupling agents like silanes, the bonding between the matrix and the basalt fiber gets increased which leads to the exceptional improvement of the mechanical properties [35].

Jamshaid et al., have asserted that basalt fibers (BF) can be really considered as the material of our future for a green and sustainable development. BF is known as the green industrial material of the century, combines ecological safety, natural longevity and many other characteristics better than glass and carbon fiber. Further, basalt is 100% inert, that is, it has no toxic reaction with air or water, and is non-combustible and explosion proof. The BF is now being a popular choice for the material scientist for the replacement of steel and carbon fiber due to its high rigidity and low elongation or extension at break. Its supreme persistence value makes it as a useful reinforcement material in the present and also for the future era to come [36].

Mokhtaret al., have studied the mechanical properties of basalt fiber and high density polyethylene (BF/HDPE) composite. However, the excellent performance of carbon fiber also been followed by basalt fiber. Basalt fiber as a natural fiber product showed good results and better than E-glass fiber in overall mechanical evaluation. The report also suggested that BF/HDPE composite can also totally eliminate the influence of synthetic fiber applications such as carbon and glass fibers in the future [37].

1.6. Fiber Treatment Methods

Reduction of surface flaws due to mercerization is responsible for higher strength. Mercerized flax fiber reinforced showed better mechanical properties than raw flax and methyl methacrylate grafted mercerized flax (MF_x.g-MMA) reinforced
composites. Kaith et al., have investigated that the Grafting of methyl methacrylate (MMA) onto flax has increased the resistance toward water because MMA grafted onto flax fiber has less affinity for water than the ungrafted fiber. Grafting in the presence of redox initiator results in increase in surface flaws and hence weakened the fiber [38].

Goriparthi et al., investigated the mechanical, thermal and wear performance of jute fiber reinforced bio composites as a function of fiber surface treatments. FTIR spectroscopic studies revealed that surface modification of the fiber occurs after every fiber treatment. Surface treatments resulted in improvement of tensile and flexural properties and reduction in impact strength. It is observed that trimethoxy methyl silane treatment enhances fiber matrix adhesion and improve the abrasive wear resistance of the jute fiber reinforced composites [39].

Xie et al., investigated that most established silanes used for natural fiber/polymer composites are trialkoxysilanes bearing a non-reactive alkyl or reactive organofunctionality. They have reported that proper treatment of fibers with silane can increase the interfacial adhesion to the target polymer matrices. Also it improved the mechanical and outdoor performance of the resulting fiber/polymer composites [40].

Guo et al., have professed that the air–plasma treatment of Kevlar fabric have increases the anti-wear, friction-reducing abilities and load-carrying capacity of Kevlar fabric/phenolic composites. As a result, the tribological performance of the Kevlar fabric/phenolic composites with air–plasma-treated Kevlar fabrics has been improved significantly [41].
1.7. Fabrication of Composites

The fabrication methodology of a composite part depends mainly on three factors: (i) the characteristics of constituent matrices and reinforcements, (ii) the shapes, sizes and engineering details of products and (iii) end uses. The composite products are too many and cover a very wide domain of applications ranging from an engine valve, or a printed circuit board laminate, or a large-size boat hull or to an aircraft wing. The fabrication technique varies from one product to the other. The matrix types (i.e., whether they are plastics, metals or ceramics) play a dominant role in the selection of a fabrication process. Similar process cannot be adapted to fabricate an engine blade made with fiber reinforced plastics and metal matrix composites.

The process parameters may also have to be modified, even when one uses the same matrix type, but two different matrices. For example, the processing with phenolic requires additional heating, whereas epoxies can be processed under ambient conditions. Particulate reinforcements and short fibers are mixed with resin to produce either bulk moulding composite compounds (BMCs) or sheet moulding composite compounds (SMCs) which are then used as base materials to fabricate composite parts. One method commonly used with BMCs is the injection moulding in which the BMC is heated and then injected into the mould cavity.

On the other hand, the comparable moulding method used for woven fiber fabrics is the resin injection moulding. The process parameters like temperature, injection pressure and curing time vary from one method to the other. Moreover, a composite car body panel, though highly curved and complex in shape may be compression moulded, while a spar stiffened helicopter rotor blade may have to be fabricated using filament winding and other moulding methods.
Further, the accuracy and sophistication required to fabricate an aircraft composite wing section may not be necessary while fabricating a composite bridge deck or a silo. There are two important stages in all moulding processes: laying and curing. The laying is the process in which moulding materials are laid on a mould in the mould cavity or on the mould surface that conforms to the shape of the part to be fabricated. The process of curing helps the resin to set, thereby providing the fabricated part a stable structural form. Moulding methods used for the fabrication of polymers may be classified into matched die mould, contact mould or open mould, filament winding and pultrusion.

Compression moulding is a commonly used matched-die moulding method. It is employed in fabrication of automobile body panels, housings for electrical appliances and machines, covers, sinks and several other parts. The moulds can have a single cavity or multiple cavities with complex curved shapes with heating provisions. The pressure is applied by mounting the moulds in a mechanical or hydraulic press or by some external means. On application of pressure and temperature, the mould material softens and then flows and fills the mould cavity. The curing is further accelerated by continuation of heat and pressure. The dimensions close to those of the desired finished part can be obtained in compression moulding, which reduces, subsequent trimming and machining. The moulding material is laid on the mould and then the moulds are closed. A barrier along the edge prevents the resin to flow out. The depth of the barrier also controls the thickness of the part. Heat and pressure are applied during curing. Once the curing is complete, the mould is opened and the part is removed.
The diffusion bonding employs the matrix in the solid phase, in the form of sheet or foil. Composite laminates are produced by consolidating alternate layers of precursor wires or fiber mats and metal matrix sheets or foils under temperature and pressure. The precursor wires are collimated filaments held together with a fugitive organic binder. This is achieved either by winding binder-coated filaments onto a circular cylindrical mandrel or by spraying the binder on the filaments that are already wound on a mandrel. When the solvent is evaporated, the fiber-resin combination forms a rolled fiber mat on the mandrel surface. The binder resin in precursor wires and fiber mats decomposes at a high temperature without leaving any residue.

A number of products ranging from flat plates to curved engine blades have been fabricated using the diffusion bonding technique. One interesting example is the 3.6m long high gain antenna boom that acted as a wave guide for the Hubble space telescope. Several other composites, for example, boron, beryllium and steel fibers in aluminium alloy matrix have been manufactured using the diffusion bonding process [42].

1.8. Differential Scanning Calorimetry (DSC)

Differential Scanning Calorimetry (DSC) is one of the most frequently employed thermal analysis methods. It can be used to analyze nearly any energetic effect occurring in a solid or liquid during thermal treatment. It is possible to analyze Specific heat capacity, Melting & Crystallization behavior, Solid-Solid transitions, Polymorphism, Phase transitions/diagrams, Liquid crystal transitions, Eutectic purity, Degree of crystallinity, Glass transition temperatures, Cross-linking reactions, Oxidative stability, Decomposition onset, Compatibility, Purity Determination and Thermo kinetics. The measures of Degree of crystallinity, Glass transition
temperatures and Decomposition onset are of particular importance in this research. DSC systems operate according to the heat flux principle.

With this method, a sample and a reference are subjected to a controlled temperature program (heating, cooling or isothermal). The actual measured properties are the temperature of the sample and the temperature difference between sample and reference. From the raw data signals, the heat flow difference between sample and reference can be determined. DSC is used widely for examining polymeric materials to determine their thermal transitions. The observed thermal transitions can be utilized to compare materials, although the transitions do not uniquely identify composition. The composition of unknown materials may be completed using complementary techniques such as IR spectroscopy.

Melting points and glass transition temperatures for most polymers are available from standard compilations, and the method can show polymer degradation by the lowering of the expected melting point which depends on the molecular weight of the polymer and thermal history, so lower grades may have lower melting points than expected. The percent crystalline content of a polymer can be estimated from the crystallization/melting peaks of the DSC graph as reference heats of fusion. DSC can also be used to study thermal degradation of polymers using an approach such as Oxidative Onset Temperature/Time (OOT).

An airtight sample chamber is necessary to study the stability of oxidation of samples. Usually, such tests are done isothermally (at constant temperature) by changing the atmosphere of the sample. First, the sample is brought to the desired test temperature under an inert atmosphere, usually nitrogen. Then, oxygen is added to the system. Any oxidation that occurs is observed as a deviation in the baseline. Such
analysis can be used to determine the stability and optimum storage conditions for a material or compound. DSC is widely used in the pharmaceutical and polymer industries. For the polymer chemist, DSC is a handy tool for studying curing processes, which allows the fine tuning of polymer properties. The cross-linking of polymer molecules that occurs in the curing process is exothermic, resulting in a positive peak in the DSC curve that usually appears soon after the glass transition.

1.9. Thermo Gravimetric Analysis (TGA)

Thermo Gravimetric Analysis (TGA) is a technique in which the mass of a substance is monitored as a function of temperature or time as a sample specimen is subjected to controlled temperature in a controlled atmosphere. In other words, TGA is a technique by which changes in weight of a material is recorded upon changing its temperature. TGA measures a sample’s weight as it is heated or cooled in a furnace. Inorganic materials, metals, polymers and plastics, ceramics, glasses, and composite materials can be analyzed in this method. TGA can be used to evaluate the thermal stability of a material. In a desired temperature range, if a species is thermally stable, there will be no observed mass change. Negligible mass loss corresponds to little or no slope in the TGA trace. TGA also gives the upper use temperature of a material. Beyond this temperature the material will begin to degrade.

TGA may be more useful for decomposition behavior determination. Impurities in polymers can be determined by examining thermograms for anomalous peaks, and plasticizers can be detected at their characteristic boiling points. In addition, examination of minor events in first heat thermal analysis data can be useful as these apparently “anomalous peaks” can in fact also be representative of the process or storage thermal history of the material or polymer physical aging.
Comparison of first and second heat data collected at consistent heating rates can allow the analyst to learn about both polymer processing history and material properties.

TGA determines temperature and weight change of decomposition reactions, which often allows quantitative composition analysis. It may be used to determine water content. TGA enables analysis of reactions with air, oxygen, or other reactive gases. It can also be used to measure evaporation rates, such as those to measure the volatile emissions of liquid mixtures. It helps in identifying plastics and organic materials by measuring the temperature of bond scissions in inert atmospheres or of oxidation in air or oxygen. It can be used to measure the weight of fiberglass and inorganic fill materials in plastics, laminates, paints, primers, and composite materials by burning off the polymer resin.

TGA has a wide variety of applications, including analysis of ceramics and thermally stable polymers. Ceramics usually melt before they decompose as they are thermally stable over a large temperature range, thus TGA is mainly used to investigate the thermal stability of polymers. Most polymers melt or degrade before 200°C. However, there is a class of thermally stable polymers that are able to withstand temperatures of at least 300°C in air and 500°C in inert gases without structural changes or strength loss, which can be analyzed by TGA [43]. High performance fibers can be compared using TGA as an evaluation of thermal stability. High performance fibers used in brake shoe materials must remain strong enough mechanically so as to provide effective braking through friction while protecting the brake drums at the same time. The thermal and photochemical degradation of the fibers will cause the mechanical properties of the break shoe to decrease, effectively
rendering them useless. Thus, thermal stability is a key property to be considered when choosing the right brake shoe material.

1.10. Scanning Electron Microscope (SEM) Analysis

A Scanning Electron Microscope (SEM) is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that can be detected and that contain information about the sample's surface topography and composition. The electron beam is generally scanned in faster scan pattern, and the beam's position is combined with the detected signal to produce an image. SEM can achieve resolution better than a nanometer. Specimens can be observed in high vacuum, in low vacuum, in wet conditions (in environmental SEM), and at a wide range of cryogenic or elevated temperatures.

The most common SEM mode is detection of secondary electrons emitted by atoms excited by the electron beam. The number of secondary electrons that can be detected depends, among other things, on the angle at which the beam meets the surface of specimen, i.e. on specimen topography. By scanning the sample and collecting the secondary electrons with a special detector, an image displaying the topography of the surface is created. For conventional imaging in the SEM, specimens must be electrically conductive, at least at the surface, and electrically grounded to prevent the accumulation of electrostatic charge at the surface. Metal objects require little special preparation for SEM except for cleaning and mounting on a specimen stub.
Nonconductive specimens tend to charge when scanned by the electron beam, and especially in secondary electron imaging mode, this causes scanning faults and other image artifacts. They are therefore usually coated with an ultrathin coating of electrically conducting material, deposited on the sample either by low-vacuum sputter coating or by high-vacuum evaporation. Conductive materials in current use for specimen coating include gold, gold/palladium alloy, platinum, osmium, iridium, tungsten, chromium, and graphite. Additionally, coating with heavy metals may increase signal/noise ratio for samples of low atomic number. An alternative to coating for some biological samples is to increase the bulk conductivity of the material by impregnation with osmium using variants of the OTO staining method (O-osmium, T-thiocarbohydrazide, and O-osmium).

Non-conducting specimens may be imaged uncoated using environmental SEM (ESEM) or low-voltage mode of SEM operation. Environmental SEM instruments place the specimen in a relatively high-pressure chamber where the working distance is short and the electron optical column is differentially pumped to keep vacuum adequately low at the electron gun. The high-pressure region around the sample in the ESEM neutralizes charge and provides an amplification of the secondary electron signal.

Low-voltage SEM is typically conducted in a field emission guns FEG-SEM, which is capable of producing high primary electron brightness and small spot size even at low accelerating potentials. Operating conditions to prevent charging of non-conductive specimens must be adjusted such that the incoming beam current is equal to sum of outgoing secondary and backscattered electrons currents. It usually occurs at accelerating voltages of 0.3–4 kV. SEMs do not naturally provide 3D
images. However 3D data can be obtained using an SEM with different methods such as photogrammetry (2 or 3 images from tilted specimen), photometric stereo also called “shape from shading” and photometric single image topography reconstruction [44].

1.11. Wear and Friction

Wear is related to interactions between surfaces and specifically the removal and deformation of material on a surface as a result of mechanical action of the opposite surface. The need for relative motion between two surfaces and initial mechanical contact between asperities is an important distinction between mechanical wear compared to other processes with similar outcomes [45]. Wear can also be defined as a process where interaction between two surfaces or bounding faces of solids within the working environment results in dimensional loss of one solid, with or without any actual decoupling and loss of material.

Several standard test methods exist for different types of wear to determine the amount of material removal during a specified time period under well-defined conditions. But all test methods have inbuilt limitations and do not give a true picture in every aspect. This can be attributed to the complex nature of wear, in particular industrial wear, and the difficulties associated with accurately simulating wear processes. An attrition test is a test carried out to measure the resistance of a granular material to wear.

Wear test for brake friction materials can be performed using a pin-on-disc machine in a laboratory. Such a test would determine the wear and co-efficient of friction on metals. It is also used for evaluating the rate of wear and ranking of
materials. The pin-on-disc wear and friction tester is operated with a pin positioned perpendicular to the flat circular disc. The test machine causes the disc specimen to revolve about the disc center and the sliding path is a circle on the disc surface. The pin-on-disc wear test confirms to ASTM G 99 test standard. The other properties of materials that can be determined by this tester are effects of load and speed on dry adhesive wear of materials, stick-slip phenomenon in dry contacts, adhesive wear of coatings, and adhesive wear of self-lubricating materials and can help in generating wear maps.

1.12 Methods of Wear Testing and Friction Properties

Tayeb et al., analysed the friction coefficient, disc temperature, and wear rate characteristics of four different non-commercial brake pad materials evaluated using a small scale tribo-tester of pad-on-disc type under the dry condition. The friction and wear characteristics of brake pads are determined by the transfer and back transfer films, formation, growth and disintegration of contact plateaus. Increase in the COF with pressure appears due to more contact plateaus becoming engaged at the sliding interface as a result of surface asperities deformation and flattening. Increasing contact pressure causes more exposure of relatively higher wear resistance constituents (steel fibers) to sliding against the disc which eventually resulted in less wear rate. The presence of the cavities or craters due to disintegration contributed differently during dry and wet braking. During dry braking, they acted as debris collectors and sometimes the debris is compacted and remained inside the cavities and became integrated with the surfaces. This process in addition to the transfer film caused the wear rate to decrease with increasing the pressure during dry tests. NF1 showed the best wear performance among all the brake pads tested [46].
Cho et al., have investigated the effect of the ingredients on the friction characteristics of composite materials. Friction characteristics such as the friction coefficient, fade, wear resistance, and noise propensity were measured by using a small scale friction tester. They reported that the friction coefficient at moderate temperatures is dependent on the hardness and morphology of ingredients. The coefficient of friction increased with increase of phenolic resin and MgO. Potassium titanate, copper, zircon, and rubber decrease the friction coefficients. The wear resistance was improved when friction material has higher contents of rock wool, zircon, phenolic resin, and Ca (OH)$_2$. The occurrence of friction-induced noise was aggravated when the friction material contained larger amounts of phenolic resin, rock wool, zircon, and MgO [47].

Eriksson et al., alleged that the area of real contact between interfaces is concentrated to small spots confined within the plateaus. The plateaus have a relatively long life while the areas of real contact are constantly shifting due to wear and deformation and surface roughness on the disc surface. Further they concluded that the contact surfaces between the pad and the disc may vary with respect to size, properties and composition [48].

Ravi et al., have proclaimed that the particle size exhibits an inverse relationship with wear rate. For a given weight fraction of reinforcement, larger particle size offers higher wear resistance, because small particles are pulling out from the matrix as the interfacial strength between the particle-matrix remains weak due to small surface contact area. An increase in the addition of fly ash restricts the deformation of the matrix material with respect to load, hence the wear rate for higher volume fraction is low. The sliding speed shows a direct relationship with wear rate.
At high speed micro thermal softening of matrix material may take place lowering the bonding efficiency of the fly ash with the matrix material. Finally they reported that the Coefficient of friction varies directly with fly ash particle size [49].

Filip et al., have features identified friction layer and the friction film on the friction surfaces of samples involved in friction tests. The friction layer and carbonaceous friction film developed on the friction surfaces of all investigated materials. While the carbonaceous friction film demonstrated analogous structure, thickness, and similar crystallite size, the structure and chemical composition of the friction layer strongly depends on applied friction conditions[50].

Yousif et al., investigated the adhesive wear of betel nut fiber reinforced polyester (BFRP) composite tested under different normal loads, sliding distances and contact conditions. Under dry condition, the interfacial adhesion of the fiber is high compared to the wet, i.e. there was no pull out. The wear mechanism of BFRP composite was dominated by macro and micro cracks, debonding and fiber pull-out. Under dry contact conditions, the counter face roughness was increased significantly after the test due to film transfer [51].

El-Tayeb investigated the adhesive friction and wear characteristics of sugarcane fiber/polyester and glass fiber/polyester composites sliding against smooth counter face. It has been found that sugarcane fiber reinforced polyester composite offers a good degree of wear resistance and friction coefficient comparable to glass fiber reinforced Polyester when sliding against stainless steel. Thus, sugarcane fiber has a strong potential to reinforce polyester and proved to be a quite competitive to glass fiber. Sugarcane fiber (SCF) being non-abrasive fiber and glass fiber (GF) being abrasive fiber, both contributed differently to the wear process at the interface, i.e.,
smooth protective layers (back transfer polymer films) contributed to mitigate the wear rate and enhance the bonding between SCF and matrix [52].

1.13. Wear Maps

The range of sliding conditions within which mild wear occurs in materials sliding components can be adequately predicted through the wear mechanism map. The trends of wear rate and the associated transitions between mild wear and severe wear could also be estimated from the map. The features on the resultant worn surfaces could be predicted. Although the wear mechanism map can be constructed primarily based on data from a particular configuration, it can be applied to other test geometries after the sliding conditions have been appropriately converted to their normalized values. This expands the applicability of the map. The wear mapping methodology can be applied to many alloys and their composites. It is suggested that these maps are able to describe adequately the behaviors of materials when particular mechanism is dominantly contributing to most of the wear and also they could be used to predict the broader wear characteristics of these alloys during sliding [53].

Wear maps are useful to designers and engineers when they have to make engineering decisions where wear is one of the major considerations. Wear maps can also play the role of a diagnostic tool during failure analysis. These maps combine wear rates and wear mechanisms observed under a certain set of sliding (or operating) conditions and at the same time provide a framework for the overall wear behaviour
of the materials in relative motions. Wear mapping is slowly gaining acceptance as a user friendly approach to the presentation of wear related information [54].

Singh et al., have done a systematic investigation on the tribological characteristics of untreated KFRP (kenaf fiber reinforced polyurethane composite), neat polyurethane and treated kenaf fiber reinforced polyurethane composite. Treated KFRP composites performed better under higher applied loads than untreated KFRP and neat polyurethane. In other words, specific wear rates are lower at steady state under higher applied loads.[55].

Gang Tang et al., have concluded that the addition of molybdenum disulphide (MoS₂) greatly affected the tribological properties of the polyamide 6 (PA6) composites. An appropriate content of solid lubricants have improved the tribological properties of aramid-filled PA6 composites greatly. The optimal volume content of MoS₂ is to be 10 % Vf obtained the best combination of friction coefficient and wear rate [56].

Nirmal et al., have reported that when fibers are treated with 6% NaOH treatment it enhanced the wear resistance of the treated betelnut fiber reinforced polyester (T-BFRP) composite under dry/wet contact conditions compared to the untreated bamboo fiberone [57].

Yousif et al., have asserted that the predominant wear mechanisms were debonding and breakage of fibers associated with fragmentation and fracture at the resinous regions. The wear performance of the treated oil palm fiber reinforced polyester (T-OPRP) composite reduces due to the weakening process incurred by the fibers during the aging process in different immersion solutions [58].
Yousif et al., concluded that the treated betelnut fiber reinforced epoxy (T-BFRE) composite experiences higher weight losses when subjected to high sliding velocities. Higher frictional values are evidenced during low sliding velocities due to mechanical interlocking of the T-BFRE composite and the abrasive sand particles asperities. The predominant wear mechanisms for the T-BFRE composite sliding under fine sand particles are detachment of fibers, plastic deformation and scratching on the resinous regions [59].

Srinivasan et al., have reported that the transition of mild wear to severe wear or severe wear to ultra severe wear transition plays an important role in wear mechanism maps. They also concluded that mild to severe wear transition could be attributed to excess contact pressure over the material hardness or other critical pressure related to material yield or fracture. The sliding surface with different contact areas of the mated surface occurs due to the rolling sliding motion of materials and results in wear shape inconformity between the sliding surfaces. This wear shape inconformity enhances with the sliding time and results in large contact pressure, thus leading to wear transition [60].

Chen et al., have discussed the wear transition of magnesium alloy (AZ91). They sub classified mild wear regime in to two sub-regimes namely an oxidational wear and a delamination wear regime. Unlike the transition from mild to severe wear normally accompanied by an abrupt wear rate change, this transition occurred gradually and does not have a noticeable effect on the mild wear rates. In the severe wear regime, two other sub-regimes namely severe plastic deformation induced wear and melt wear regimes have been identified. The contact surfaces reached a thermal equilibrium during mild wear which produced steady state wear rates. Wear rates and
contact temperatures are increased with the sliding distance during severe wear. The transition to severe wear is controlled by a critical surface temperature criterion, rather than a load or sliding speed criterion [61].

Pasaribu et al., have defined mild wear as, when a relatively smooth wear track is formed with a specific wear rate less than $10^{-6}$ mm$^3$/Nm and severe wear is defined when rough wear track is formed with a specific wear rate larger than $10^{-6}$ mm$^3$/Nm. The combined thermal and mechanical severity parameter of the developed model shows improvement in predicting mild to severe wear transition of ceramics, particularly in the region where wear is induced by both mechanical loading and thermal loading [62].

An empirical equation is developed by Riabi et al., to show that the transition from mild to severe wear in grey cast iron occurred when the energy generated at the contact surfaces is increased. According to the wear map constructed, transition boundaries between the mild to severe wear and the ultra mild to mild wear regimes are linear on the log load versus log velocity scale. The morphology of worn surfaces reveals the fracture of graphite flakes and matrix which led to the formation of large size debris in the mild wear regime, which is otherwise dominated by oxidative wear. The transferred cast iron debris particles that are hardened during this process played a role in the transition to the severe wear by facilitating surface deformation [63].

Kato et al., have classified wear regimes as mild and severe wear based on view points of surface roughness and wear rate. In mild wear, the wear surface roughness is smaller than the grain size by about one-tenth and the wear rate is in the range of $10^{-9}$ to $10^{-6}$ mm$^3$/ (N m) whereas in severe wear, the wear surface roughness is in the order of grain size, and the wear rate is in the range of $10^{-6}$ to $10^{-2}$
mm$^3$/Nm). The critical conditions for the transition between mild and severe wear are given by the certain values of mechanical severity of contact and thermal severity of contact. The knowledge of wear, wear transitions and wear mechanisms for a material pair enables realistic wear model development. The main issue of constructing the wear mechanism maps is complication in selecting the control parameters for a given chemical composition of materials [64].

Farias et al., have professed that adhesive effects in the counter surfaces are generated by the presence of lubricants with the result of increase of the static coefficient of friction. It has been inferred that an increase of the static coefficient of friction takes place with the stiffness decrease of the counter face material. The influence of the filler depends on the contacting surface [65].

1.14 Hardness

Hardness was measured to identify in order to confirm proper curing and uniform mixing of brake materials. The surface of the samples was carefully prepared using silicon carbide papers. At least five indentations were made from the center to the edge of the samples to obtain an accurate value of the hardness for each sample and an average value was obtained [66].

1.15 Fuzzy C Means Clustering (FCM)

Clustering involves the task of dividing data points into homogeneous classes or clusters so that items in the same class are as similar as possible and items in different classes are as dissimilar as possible. Clustering can also be thought of as a form of data compression, where a large number of samples are converted into a small number of representative prototypes or clusters. Depending on the data and the
application, different types of similarity measures may be used to identify classes, where the similarity measures may be used to identify classes, where the similarity measure controls how the controls and how the clusters are formed. Some examples of values that can be used as similarity measures include distance, connectivity and intensity.

Fuzzy C-Means (FCM) is a data clustering technique in which a dataset is grouped into n clusters with every data point in the dataset belonging to every cluster to a certain degree [67]. For example, a certain data point that lies close to the centre of a cluster will have a high degree of belonging or membership to that cluster and another data point that lies far away from the centre of a cluster will have a low degree of belonging or membership to that cluster. In non-fuzzy or hard clustering, data is divided into crisp clusters, where each data point belongs to exactly one cluster. In fuzzy clustering, the data points can belong to more than one cluster, and associated with each of the points are membership grades which indicate the degree to which the data points belong to the different clusters. FCM clustering finds many applications in data mining.

Fuzzy c-means (FCM) is a data clustering technique in which a dataset is grouped into n clusters with every data point in the dataset belonging to every cluster to a certain degree. For example, a certain data point that lies close to the center of a cluster will have a high degree of belonging or membership to that cluster and another data point that lies far away from the center of a cluster will have a low degree of belonging or membership to that cluster [68].

Srinivasan et al., have employed fuzzy clustering method (FCM) for estimation of flank wear in face milling. Various signals such as acoustic emission
(AE), surface roughness, and cutting conditions (cutting speed and feed) have been used to estimate the flank wear. Wang et al., attempted various methods for tool wear classification and it is concluded that fuzzy clustering techniques may provide a realistic solution to the classification of tool wear states. Unlike fuzzy clustering methods used previously, which postulate cutting condition parameters as constants and define clustering centres subjectively, this paper presents a fuzzy clustering method based on filtered features for the monitoring of tool wear under different cutting conditions. The validity and reliability of the method are experimentally illustrated using a CNC machining centre for milling [69].

1.16. Motivation for this study

It is evident from the available literature that enormous amounts of studies have been carried out in synthetic fiber used in polymer matrix brake friction composites. The inability of synthetic fiber to exhibit good tribological performance is revealed. In order to enhance it, there is a need for natural fiber to be reinforced with polymer matrix composites. It is observed that the study on wear characteristics of polymer matrix brake friction composites is one of the important areas of research in automobile applications. Moreover, the wear behaviour of polymer matrix brake friction composites differs significantly from the wear behaviour of conventional metals, alloys and ceramics.

There is a lack of wealthy experimental data for thermal and wear studies of polymer matrix brake friction composites, while there is plenty of experimental data exist in wear studies of conventional metals and their alloys. Furthermore, there is a limitation for the field engineers to adopt parameters for wear behaviour of polymer matrix brake friction composites. Hence, there is a need for carrying out thermal and
wear studies on polymer matrix brake friction composites with different wear parameters.

Wear mechanisms and their transition are important phenomena in understanding the change in wear rate with the operating conditions. Contrasting conventional metals and their alloys, very few studies have been reported which dealt with wear mechanisms and their transitions that involved in influencing the wear behaviour of polymer matrix brake friction composites. However, the development of such maps is complicated by the fact as polymer matrix brake friction composites display properties, which vary over a particular range and strongly dependent on its microstructure of worn out surface. Also in conventional wear mechanism maps, it is very difficult to classify the boundaries between the different mechanisms. Hence it is proposed to employ FCM for the classification of mechanisms developed requires validation by SEM observations of worn out specimens. Further it is necessary to find whether the thermal studies can be correlated with wear studies.

1.17 Organization of the Thesis

The thesis is organized as follows:

Chapter 1 reviews the available literature relevant to the present study
Chapter 2 it gives the experimental procedure used in this study
Chapter 3 it shows the thermal behavior of brake friction materials
Chapter 4 it shows the wear behavior and hardness of brake friction materials
Chapter 5 it gives the conclusion for this study. Also the work to be continued for future work has been mentioned.

Chapter 6 Reference
1.18. Flow chart of intended research work

Fig. 1.1 shows the work plan to be executed for the present investigation.
1.19 Objectives of this Research

- To study the feasibility of incorporating flax, basalt and flax-basalt hybrid fibers as reinforcements on phenolic resin matrix to fabricate fiber reinforced composites.
- To study the thermal characteristics of polymer matrix composites using Differential Scanning Calorimetry (DSC) and Thermo Gravimetry (TGA) Analysis.
- To study the friction and wear behaviour of polymer matrix composites using Pin on disc wear tester under different sliding conditions.
- Development of wear mechanism map using Fuzzy Clustering Method.
- To find whether there is any correlation between thermal and wear characteristics of composite samples used in this study.