Forming Analysis of Polymer Matrix Composite

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Abstract

Fields like aerospace and automobiles are always in need of lighter materials with good strength. Conventional materials do not satisfy these requirements. Many structural parts used in aerospace and automobiles field are of complex shapes which can be manufactured by forming processes. Therefore use of polymer matrix composites having light weight with good process ability, in these field is increasing. For forming of polymer matrix composites it is important to understand the effect of different design and processing parameters on formability of polymer matrix composites. The present paper illustrates the drawing analysis of polymer matrix composites. Composites sheets were made with the nettle fiber, woven glass fiber and random glass fiber as reinforcement in with thermoplastic (polypropylene and polyethylene) and thermosetting (epoxy) matrices. These polymer matrix composites were fabricated on the compression molding machine and along with the hand lay-up process. The drawing process was carried out on the polymer matrix composites with the experimental set up. Parameters used for investigation are punch shape, thickness of sheet, different fiber material and different polymer matrices. Influence of these parameters has been investigated with respect to average failure load and drawing limit measured during the drawing operations. Results indicate that the failure load of woven glass fiber reinforced composite at varying thickness viz. 1mm, 2mm, 3mm in 5 seconds and 10 seconds have far better load carrying capacity in comparison to the random glass fiber and nettle fiber with all type of used matrices based composites with the chamfered tool.

Key words: Composites; Reinforcement; Thermoplastic and Thermosetting;

Introduction

Composite materials result from the association of at least two chemically and geometrically different materials. “Composite material” commonly means reinforcing material embedded in a material called matrix, which has much lower strength and stiffness. The bond between the reinforcing material and the matrix created during the preparation phase of the composite material and mechanical properties are fundamentally effected by the bond shall.

1.1 Components of Composite Material:

1.1.1 Matrices

The matrix of a composite has several functions; the reinforcement is hold by the binder in place, external loads are transferred to the reinforcement, and the reinforcement is protected from environmental exposure. Moreover the matrix redistributes the load to the surrounding fibers when a fiber fractures and supports the fiber to prevent buckling in compression. Matrices are divided into three categories, depending on material used, as follows:

- Polymers: They can be easily processed, more resistant to chemicals than are metals. They have lower strength and modulus and lower temperature use limits. Commonly used polymers for composites are epoxy, polyester, polyether, ether ketone, polypropylene etc.
- Metals: They are strong and tough. They can be plastically deformed, and they can be strengthened by wide variety of methods. Commonly used matrix materials are aluminum, copper, nickel etc.
- Ceramics: They are hard and brittle. Generally they consist of one or more metals combined with non metal such as oxygen, carbon, or nitrogen. Therefore ceramics have lower failure strains and low toughness or fracture energies. But they have high elastic moduli, low densities and can withstand very high temperatures. Commonly used ceramics for composites are borosilicate glass, soda glass, mullite etc.

1.1.2 Reinforcement

Their purpose is to ensure the mechanical function of composite material. They are primarily intended to carry the structural loads, the composite is subjected to the reinforcement therefore to a significant degree determines stiffness and strength of the composite. Reinforcement is used in various forms, as particles, flakes, whiskers, short fibers, continuous fibers or sheets. Depending upon materials reinforcements can be classified as follows:

- High strength fibers: glass, carbon, boron
- Synthetic fibers: aramid , nylon, polyester
- Ceramic fibers: silica, alumina.

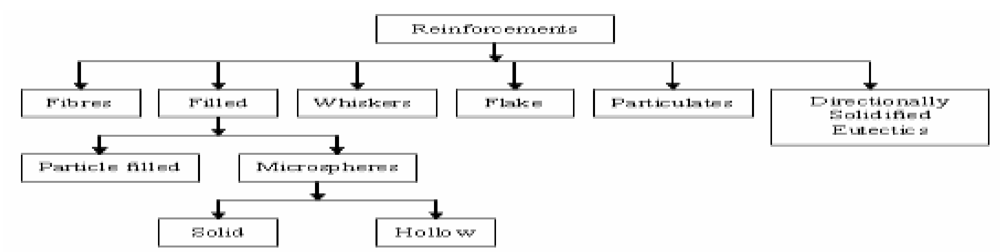


Fig 1.1 Classifications of Reinforcements

1.2 Classification of Composites

Composites are classified at two different levels

- In first level matrix are constituents by the main category of composites Metal matrix composite, ceramic matrix composite and organic matrix composites.
- In second level classification are done on the behalf of reinforcement type composite formed with fibers, composite formed with particulates etc.

1.2.1 Organic Matrix Composites

1.2.1.1 Polymer Matrix Composites (PMC)/ Carbon-Carbon Composites or Carbon Matrix Composites.

Polymers make ideal materials as they can be processed easily, possess lightweight, and desirable mechanical properties. It follows, therefore, that high temperature resins are extensively used in aeronautical applications.

Two main kinds of polymers are thermosets and thermoplastics. Thermosets have qualities such as a well-bonded three-dimensional molecular structure after curing. They decompose instead of melting on hardening. Merely changing the basic composition of the resin is enough to alter the conditions suitably for curing and determine its other characteristics. They can be retained in a partially cured condition too over prolonged periods of time, rendering. Thermosets are very flexible. Thus, they are most suited as matrix bases for advanced conditions fiber reinforced composites. Thermosets find wide ranging applications in the chopped fiber composites form particularly when a premixed or molding compound with fibers of specific quality and aspect ratio happens to be starting material as in epoxy, polymer and phenolic polyamide resins. Thermoplastics have molecular structure of ane or two diminutions and they assumed to be at temperature in elevation and show exaggerated melting point. Another advantage is that the softening process when temperature is more and when it cools it regain its properties, facilitating applications of conventional compress techniques to mould the compounds. Resins reinforced with thermoplastics now comprised an emerging group of composites. The theme of most experiments in this area to improve the base properties of the resins and extract the greatest functional advantages from them in new avenues, including attempts to replace metals in die-casting processes. In crystalline thermoplastics, the reinforcement affects the morphology to a considerable extent, prompting the reinforcement to empower nucleation. Whenever crystalline or amorphous, these resins possess the facility to alter their creep over an extensive range of temperature. But this range includes the point at which the usage of resins is constrained, and the reinforcement in such systems can increase the failure load as well as creep resistance. Figure 1.2 shows kinds of thermoplastics.

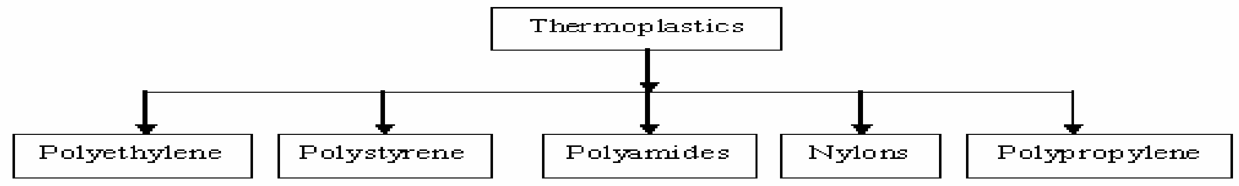


Fig 1.2. Classification of thermoplastic

A small quantum of shrinkage and the tendency of the shape to retain its original form are also to be accounted for. But reinforcements can change this condition too. The advantage of thermoplastics systems over thermosets are that there are no chemical reactions involved, which often result in the release of gases or heat. Manufacturing is limited by the time required for heating, shaping and cooling the structures. Thermoplastics resins are sold as molding compounds. Fiber reinforcement is apt for these resins. Since the fibers are randomly dispersed, the reinforcement will be almost isotropic. However, when subjected to molding processes, they can be aligned directionally. There are a few options to increase heat resistance in thermoplastics. Addition of fillers raises the heat resistance. But all thermoplastic composites tend lose their strength at elevated temperatures. However, their redeeming qualities like rigidity, toughness and ability to repudiate creep, place thermoplastics in the important composite materials bracket. They are used in automotive control panels, electronic products encasement etc. Newer developments augur the broadening of the scope of applications of thermoplastics. Huge sheets of reinforced thermoplastics are now available and they only require sampling and heating to be molded into the required shapes. This has facilitated easy fabrication of bulky components, doing away with the more cumbersome molding compounds. Thermosets are the most popular of the fiber composite matrices without which, research and development in structural engineering field could get truncated. Aerospace components, automobile parts, defense systems etc., use a great deal of this type of fiber composites. Epoxy matrix materials are used in printed circuit boards and similar areas. Figure 1.3 shows some kinds of thermosets.

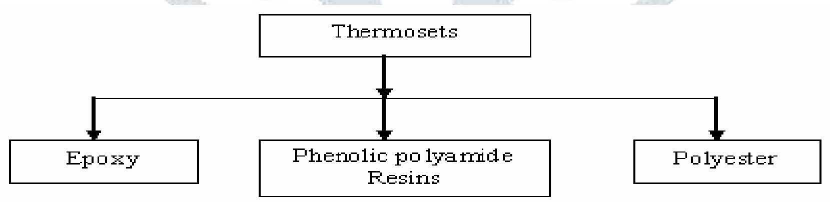


Fig 1.3 Thermosetting Materials

1.2.1.2 Metal Matrix Composites

Metal matrix composites, at present though generating a wide interest in research fraternity, are not as widely in use as their plastic counterparts. High strength, fracture toughness and stiffness are offered by metal matrices than those offered by their polymer counterparts. They can withstand elevated temperature in corrosive environment than polymer composites. Most metals and alloys could be used as matrices and they require reinforcement materials which need to be stable over a range of temperature and non-reactive too. However the guiding aspect for the choice depends essentially on the matrix material. Light metals form the matrix for temperature application and the reinforcements in addition to the aforementioned reasons are characterized by high moduli. Most metals and alloys make good matrices. However, practically, the choices for low temperature applications are not many. Only light metals are responsive, with their low density proving an advantage. Titanium, Aluminium and magnesium are the popular matrix metals currently in vogue, which are particularly useful for aircraft applications. If metallic matrix materials have to offer high strength, they require high modulus reinforcements. The strength-to-weight ratios of resulting composites can be higher than most alloys. The melting point, the service temperature of composites can be determined by physical and mechanical properties at different temperature. Most metals, ceramics and compounds can be used with matrices of low melting point alloys. The choice of reinforcements becomes more stunted with increase in the melting temperature of matrix.

1.2.1.3 Ceramic Matrix Materials (CMM)

Ceramics can be described as solid materials which exhibit very strong ionic bonding in general and in few cases covalent bonding. Ceramic-based matrix materials a favourite for applications requiring a structural material that doesn't give way at temperatures above 1500ºC. Naturally, ceramic matrices are the obvious choice for high temperature applications.

High modulus of elasticity and low tensile strain, which most ceramics posses, have combined to cause the failure of attempts to add reinforcements to obtain strength improvement. This is because at the stress levels at which ceramics rupture, there is insufficient elongation of the matrix which keeps composite from transferring an effective quantum of load to the reinforcement and the composite may fail unless the percentage of fiber volume is high enough. A material is reinforcement to utilize the higher tensile strength of the fiber, to produce an increase in load bearing capacity of the matrix. Addition of high-strength fiber to a weaker ceramic has not always been successful and often the resultant composite has proved to be weaker.

1.2.2 Classification Based on Reinforcements

1.2.2.1 Introduction to Reinforcements

Reinforcements for the composites are fibers, material particles .Fiber are basically characterized by one terribly long axis with different two axis either typically circular or close to circular. Particles don't have any most well liked orientation then will their form. Whisker has a most well liked form however are little each in diameter and length as compared to fibers.

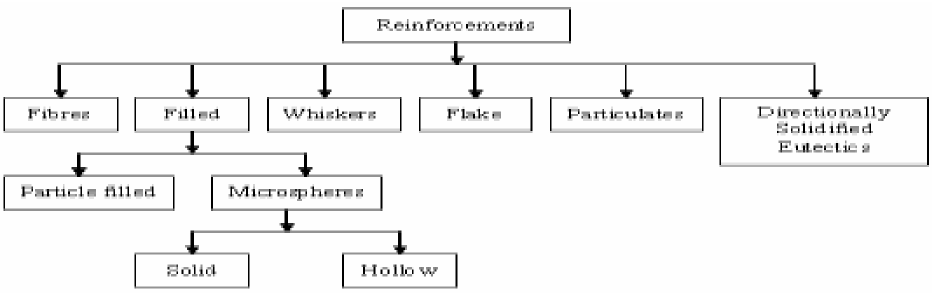


Fig.1.4 Classification of Reinforcements

1.2.2.1.1 Fiber Reinforced Composites

Fibers area unites the vital category of reinforcement, as they satisfy the specified conditions and transfer strength to the matrix constituents influencing and enhancing their properties as desired. Glass fiber area unite the earliest renowned fibers would not to reinforce materials. Ceramic and metal fibers were after observed and place to intensive use, to render composite additional immune to heat. Fibers let down of ideal performance as a result of many factors. The performance of a fiber composite is judged by its length, shape, orientation, and composition of the fibers and therefore the mechanical properties of the matrix. The orientation of the fiber within the matrix is a sign of the strength of the composite and also the strength is greatest on the longitudinal directional of fiber. This doesn’t mean the longitudinal fibers will take an equivalent quantum of load no matter the direction during which it's applied. Optimum performance from longitudinal fibers will be obtained if the load is applied on its direction. The term “fiberglass” describes a thermosetting plastic organic compound that is strengthened with glass fibers. During this manual, the lot of general terms fiber strengthened would not to describe these extraordinarily helpful material systems. The plastic resin systems confirm chemical, electrical, and thermal properties. Fibers give the strength, dimensional stability and warmth resistance. Additives give color and conform surface end, and have an effect on several alternative properties like weathering and flame retardance.

1.3 Benefits and Features of FRP

1.3.1 Resistance to Corrosion

FRP/Composites don’t rust, corrode or rot and thus they resist attack from most industrial and home chemicals. This quality has been accountable for applications in corrosive environments like those found within the chemical process and water treatment industries. Resistance to corrosion provides long life and low maintenance in marine applications from sailboats and minesweepers to seawalls and offshore oil platforms.

1.3.2 Strong and Lightweight

FRP/Composites give high strength to weight ratios extraordinary those of aluminum or steel. High strength, lightweight FRP/Composites are uniting rational choice selection whenever weight savings area unites desired, like elements for the transportation business.

1.3.3 Dimensionally Stable

FRP/Composites have high dimensional stability beneath varied physical, environmental, and thermal stresses. This can be in all foremost helpful properties of FRP/Composites**.**

1.3.4 Consolidation of Parts and Minimization of Tool

A single FRP composite molding typically replaces associate degree assembly of many metal elements and associated fasteners, reducing assembly and handling time, simplifying inventory, and reducing producing prices. One FRP/Composite tool will replace many progressive tools needed in metal stamping**.**

1.3.5 High Dielectric Strength and Low Moisture Absorption

The excellent electrical insulating properties and low wetness absorption of FRP/Composites qualify them to be used in primary support applications like c breaker housings, and wherever low wetness absorption is required.

1.3.6 Minimum Finishing

FRP/Composites may be pigmented as part of the blending operation or coated as part of the molding method, often eliminating the requirement for painting. This is often notably value effective for big elements like tub/shower units. Also, on crucial look components, a category “A” surface is achieved.

1.3.7 Low Tooling Cost

Regardless of the molding technique selected, tooling for FRP/Composites sometimes represents little a part of the merchandise value. For either large-volume mass-production or restricted runs, tooling value is often under that of multiple forming tools required to produce a similar finished part in metal.

1.3.8 Flexible to Design

No different major material system offers the planning flexibility of FRP/Composites. They vary from industrial fishing boat hulls and decks to truck fenders, from parabolic TV antennas to transit seating, and from outside lamp housings to seed hoppers. What the longer term holds depends on the imagination of today’s design engineers as they develop even additional innovative applications for FRP/Composites

1.4 Application of fiber reinforced plastic

- Fiber Reinforced composites to the Highway Infrastructure
- highway-related applications of FRP can be divided into some categories:
  a) Repair and retrofitting b) Seismic retrofitting

1.4.1 Repair and Retrofitting

FRP composites to civil structures concerned the repair and retrofitting of concrete structures exploitation outwardly secured FRP composites. This technology is fairly mature; in depth analysis results exist on bond performance, creep effects, malleability of the repairs, fatigue performance, force transfer, peel stresses, resistance to fire, and supreme strength. Carbon, glass, and aramid plates and sheet systems are readily available.

1.4.2 Seismic Retrofitting: Seismic retrofitting of concrete bridges is additionally exploitation also using FRP composites. The first application is column wrapping. This procedure, which may be employed in place of steel jackets, provides further confinement for the column. This ends up in further column ductility and may conjointly alter rebar splices with two little laps to additional absolutely develop.

Literature Review

Formability of polymer matrix composites has influence of many parameters like fiber volume fraction, fiber arrangement, fiber and matrix material, drawing parameters like punch travel speed. As polymer matrix composite have high strength to weight ratio, its use is increasing where weight of a component is important factor like in aerospace and automobile application. Many structural parts used in aerospace and automobile application are of complex shapes which can be manufactured by sheet metal forming processes.Therefore, the researchers are giving attention to the forming Formability of polymer composite sheets has influence of many parameters like fiber volume fraction, fiber of polymetric matrix composites. Work done in this is discussed here by:

2.1 Forming behavior of polymer matrix composites :

Srinivasababu et al. determined the tensile properties of various natural fiber reinforced composites. Different composites with okra, sisal and banana fiber were prepared by using hand lay-up method. **Debabrata Debnath** presented his work on the development of polymer matrix composite (epoxy resin) using bagasse fiber as reinforcement using hand lay-up process with volume fractions 10%, 15% and 20% and to study its mechanical properties at cryogenic temperature. **Yosuff et al.** studied the mechanical properties of short oil palm fibre reinforced epoxy composites in their experimentation. Empty fruit bunch (EFB) (with four different volume fractions of 5%, 10%, 15% and 20% vol) was selected as the reinforcement and epoxy as the matrix to fabricate the composite by hand lay-up techniques. **Rafeeq et al.** carried an experiment on natural fiber extracted from the date palm tree and coconut shell particle filler were used as reinforcement for epoxy matrix composites. Epoxy composite specimens reinforced with date palm fibers, coconut shell particle filler, and date palm fibers/coconut shell particle filler hybrid respectively were fabricated by hand lay-up technique.

1.1 Thermoset Matrix Composites with Synthetic Fiber Reinforcement

Abdel-Magid et al. examined the properties of an E-glass reinforced epoxy composite before and after mechanical loading and moisture conditioning. Results indicated that moisture and mechanical loading affects the mechanical properties i.e. modulus, strength, and strain of the composite material. When conditioning at room temperature for shorter durations, a slight increase in strength and a slight decrease in modulus were observed: but with conditioning for longer durations, reduction in strength was noticed. **Hasim Pihtili** studied the effects of resin content on the wear of woven roving glass fibre reinforced epoxy composites and glass fibre-polyester resin composite materials under dry conditions. Tests were conducted for two different speeds, at two different loads. The weight loss was measured and wear in the experiments was determined. **Lopresto et al.** evaluated the possibility to replace glass fibres with Basalt fiber. Mechanical tests were carried out on laminates which were reinforced with E-glass and basalt fibre, which were fabricated through vacuum bag technology. The results obtained were compared and higher young modulus, higher compressive and bending strength, high impact force and energy were observed in Basalt based laminates. **Varga et al.** developed and used new additives for enhancing the bonding properties between reinforcement and matrix and to get better characteristics of glass fibre reinforced polyester composites. Two different reinforcements (chopped glass fibre and glass woven fabric) have been used and investigated. **Han et al.** observed that strength is increased by 34.0% when carbon fibers are treated with the coupling agent. The result has shown that the by adding coupling agent, improvement in the compatibility and interfacial bonding between the reinforcement and matrix can be achieved.

1.2 Studies on Thermoplastic matrix and Natural Fiber Reinforcement

A lot of publications were made on injection molding of thermoplastics, using different reinforcements and different thermoplastic matrix, but the most work is done on Polypropylene (PP) and Poly Lactide (PLA). Referred to data available on scopus, out of 4494 papers published on injection molding of thermoplastics, 2895 papers are only with polypropylene. The main reason of using polypropylene as matrix material in most of the cases is its low cost, better mechanical properties and moldability, it also accounts for more than half of all the plastic materials used in automobiles and almost everywhere due to its recyclability too. **Yu Dong et al.** evaluated the mechanical, thermal properties and biodegradability of PLA/coir fiber bio-composites with and without alkali treatment. **Oksman et al.** reported that flax fiber reinforced PLA composites with 30-40% reinforcement; strength was comparatively 50% higher than to flax reinforced polypropylene composites. An increase in the stiffness from 3.4 to 8.4 GPa was observed in the composite. **Shih et al.** used recycled fiber from disposable chopsticks with PLA as matrix to fabricate green composites by melt-mixing process. **Bajpai at al.** compared the mechanical properties of various natural fibers with PLA as reinforcement which were fabricated by different processes. **Shibata at al.** revealed the effect of injection temperature on thermal degradation and porosity of the bagasse reinforced polypropylene composites fabricated by injection molding process. It was observed that above 185°C, incomplete filling of cavity can occur and this incompletion will increase with the increase of injection temperature. **Bledzki and Faruk** experimented on wood fiber reinforced polypropylene composites fabricated by injection molding and compression molding process with hardwood and softwood fibers. An investigation was done on the influence of different processing parameters and additives on mechanical properties of the composites. **Akil at al.** revealed that the tensile and flexural properties depend not only on the type, orientations, content and form of kenaf fiber in kenaf reinforced polymer composites but also on the type of blending/plasticizer used. **Murtuza and Akheel** made an attempt to use turmeric spent as filler to fabricate polypropylene green composite and it was observed that the tensile modulus of composites increased from 1041 to 1771 MPa with the increase in filler addition from 0 to 40 wt.%. Flexural properties of composites were also improved after reinforcement of turmeric spent into PP matrix. **Hemmati and Garmabi** showed in their experiment that the fire retardancy is another proficiency concern of the composites. Bagasse reinforced polypropylene composites were fabricated with additives including flame retardants, ultraviolet (UV) stabilizer, and antifungal and colouring agents. The addition of the flame retardant, which decomposed at high temperature could result in the NFC with a significant decrease in burning rate (up to 98%) compared to the composite without flame retardant. **Ochi** also reported that the tensile and flexural strength increase linearly when fiber content is increased up to 50% in kenaf reinforced PIA composites, which proved that kenaf fiber exhibit higher mechanical properties as compared to other natural fibers, when reinforced with PLA. **Sawpan at el.** worked on flexural properties of chemically treated random short and aligned long hemp fibre reinforced polylactic acid (PLA) and unsaturated polyester composites were also investigated over a range of fibre content (0-50 wt%). **Bledzki et al.** made an experimental work on hard wood fibre reinforced polypropylene composites. The composites were fabricated by using various processes (Extrusion-injection molding, Mixer-injection molding, Compression molding and direct Extrusion) process with 30 wt. % and 50 wt. % fibre contents. It was observed by the experimentation that extrusion and injection molding process delivered the best mechanical and physical properties in maximum cases, when compared to other fabrication processes. **Samia Sultana Mir et al.** investigated the effects of fibre treatment and fibre contents on physico mech. properties of basic chromium sulfate ($CrSO_4$)and $NaHCO_3$ (Sodium hydrogen carbonate) salts treated coir reinforced Polypropylene bio-composites. For both raw and chemically treated coir reinforced Polypropylene composites, the tensile strength initially increases and then decreased with further increase in fibre content. **Aurrekoetxea et al.** studied the effect of injection molding induced morphology on fracture behaviour of virgin and recycled PP matrix polypropylene. Results shows that the virgin polypropylene has higher micro-hardness values than the recycled one. **Han-Seung et al.** examined the effect of compatibilizing agents on mechanical properties using rice-husk flour as reinforcing filler and matrix polypropylene (PP). Four levels of filler loading were taken i.e. 10, 20, 30, 40 wt% and three levels of compatibilizing agent contents 1, 3, 5 wt%. Without using compatibilizing agent the developed composites give less tensile properties due to poor interfacial-bonding between the filler and the matrix polymer. **Rout et al.** investigated that the surface modification of coir fibres shows better mechanical properties using 2% alkali treated coir composites show better tensile strength i.e 26.80 MPa whereas 5% alkali treated coir composites show better flexural i.e 60.4 MPa and impact strength (634.6 J/m). Also the tendency of water absorption decreases due to surface modification of the fibers. SEM micrograph shows good adhesion between the matrix and fibers.

1.3 Thermoplastic Matrix Composites with Synthetic Fiber Reinforcement

Moriwaki used a direct injection molding process, in which, instead of using extrusion first for mixing of fiber with the matrix, composite parts are molded by injection molding directly using a dry blend of the resin and reinforcement. It was found that this method was more effective and better mechanical properties are observed, when compared to two step process, under higher % of reinforcement. Also, it was concluded that the extrusion process used can break the long fibers in short ones and a two step process can deteriorate the properties of glass fiber, which may lead to poor mechanical properties. **J.L. Thomason** revealed the mechanical properties of long and short glass fibre-polypropylene injection molded compounds. This allowed comparison of the mechanical properties of long and short fibre reinforced composites by using the same matrix at the same fibre properties, and also the effect of fibre diameter in short fibre compounds. The composites were prepared with a reinforcement of 40 vol%. At the same fibre diameter and fibre content long fiber polypropylene composite gives meaningful improvements in tensile and flexural properties, notched and unnotched impact resistance. The effect of lowering the fibre diameter in SF-PP resulted in increase of both, but notched impact and modulus were found unaffected by reducing diameter. **Sousa et al.** carried experimentation on high density polyethylene and short carbon fibers using an injection molding process. Two types of HDPE granules of different MFI (Melt Flow Index) were used as matrix material with 20% carbon short fiber for two different composites. It was observed that the two composite materials produced by compounding injection molding exhibit distinct mechanical properties. Lower viscosity HDPE composite exhibited more stiffness, improved strength and better impact performance. **Chifor et al.** carried experimentation on mechanical and physical properties, such as tensile strength, elongation at break, modulus of elasticity, melt flow rate (MFR), and electrical and thermal conductivities of composites with high density polyethylene matrix reinforced with 30% Al powders. The experimental data obtained from the work were found in good accordance with the theoretical data. Ultimate tensile strength (UTS) and elongation at break found to be decreased with increasing Al powder content, but the modulus of elasticity increased. **Wang and Ying** studied the thermal, tensile and dynamic mechanical properties of injection molded short carbon fiber in polypropylene matrix. In the experiment, carbon fibres were cut into short ones and mixed with polypropylene (PP) fibers. Three concentrations of SCF, 5, 15 and 25 w%, were used. Composites with good uniform dispersion of SCF in PP matrix were prepared via melting compounding in a twin-screw extruder followed by injection molding. **Hirano et al.** studied the effect of fiber length and adhesion of fiber and matrix in carbon fiber reinforced polypropylene composites. The interfacial properties were quantified in terms of the interfacial shear strength, Mechanical properties and impact resistance were evaluated. Composite strength and impact resistance were improved while increasing 1FSS and when using short fibers, but impact strength improves with decreasing inter facial shear strength. **Nevin and Ayse** used to melt mixing method for fabrication of carbon fiber reinforced polyamide 6 composites, to illustrate the effects of fiber length and content, on the mechanical, thermal and morphological properties of carbon fiber reinforced polyamide composites. The maximum numbers of fiber were detected in the range of 0-50 pm, while mechanical test results showed the increase in tensile strength by increasing the carbon fiber content. Modulus and hardness values also increased with carbon fiber reinforcement. Results show that the failure load of woven glass fiber reinforced composite at varying thickness viz. 1mm, 2mm, 3mm in 5 and 10 seconds have far batter load carrying capacity in comparison to the random glass fiber and nettle fiber with all type of used matrices based composites with the chamfered tool. It was observed that the load is almost half of 5 seconds when compared to 10 seconds, when the spherical tool is used.

Experimental Setup

3.1. Materials

- Thermoplastic material, polypropylene which is supplied by the manufacturer in a 'ready to use' pelletized form by reliance industries limited, Parc Chembur, Mumbai. Its melting temperature was 165°C and melt flow index was 10.5 g/10 min. The density of polypropylene at room temperature was 0.905 g/cm^3.

Fig.3.1 Polypropylene polymer.

- Thermoplastic material, polyethylene which is supplied by the manufacturer in a 'ready to use' pelletized form by reliance industries limited, Parc Chembur, Mumbai. Its melting temperature was 125ºC and melt flow index was 2 g/10 min. The density of polyethylene at room temperature was 0.91 g/cm^3.

Fig.3.2 Polyethylene polymer.

- Epoxy is in two parts one is the basic component and the other is cured one. Araldite is here is used as epoxy resin .It is cured at room temperature. It is used to make bonding in metals, glass etc. It is tough in nature.

Fig.3.3 Araldite epoxy adhesive.

- The fibers which are used in this study are:

Fig 3.4 Fibers clockwise from top-left nettle fiber, woven glass fiber, random glass fiber.

3.2. Methodology

In experimental work three kind of fiber have been used which are as:

a) Nettle fiber b) Woven Glass fiber c) Glass fiber

The above fibers are used to make the composite with the matrices of thermoplastic and thermoset. In thermoplastic matrices two type of thermoplastic material which are as follows:

a) Polypropylene b) Polyethylene

In thermoset matrices I used the epoxy as the matrix to make the composite with the nettle fiber, woven glass fiber and Random glass fiber.

From the above fibers and matrices the composite sheets are made with the different thickness, which are as: 1mm, 2mm, 3mm

There are two type of tool shape which I used to draw the polymer matrix composite sheets. The tool1 which used is chamfered in shape at the bottom and the tool2 is spherical in shape with the 21mm diameter. In experimental setup the dynamometer is used to get the failure load which is acting on the composite sheets when they are drawn with both of the tools. The digital displacement indicator is also used to get the displacement of the tools while drawing and to get the drawing limit of composite sheets. The sheets are drawn for the different times. The tools are applied as feed to draw the sheets for different time which are:

a) 10 seconds b) 5 seconds

3.3 Methods

3.3.1. Composites Preparation

3.3.1.1 Fabrication of Thermoplastic Based Composites

The consolidation of the PP based composite was performed at temperature165^{o}C and time 16min and PE based composite at temperature 125^{o}C and time 12min. The existing setup consists of mold plates with cavity and heating arrangement, one heating element plate is placed above the upper mold plate and one heating element plate placed below the lower mold plate. The polymer with nettle fiber, woven glass fiber, random glass fiber with desired proportion placed in the mold cavity are heated with the help of heating elements and applying desired pressure for allowing the mixture to take the shape of mold cavity. Teflon (mold release agent) is used to prevent the composite not to stick with the mold plates, the melting point of mold release agent is greater than the thermoplastic resins. After reaching to a desired temperature switch of the power supply to the heating element and mold is kept as it is for curing. The figure shows existing compression molding setup for making composites.

Fig 3.5 Setup for compression molding.

The different types of composites which have been fabricated are shown in Fig 3.6

Fig3.6. Fabricated composites of nettle fiber, woven glass fiber, random glass fiber, clockwise from the top.

3.3.1.2 Fabrication of Thermosetting Based Composite

In this method epoxy resin with nettle fiber, woven glass fiber, random glass fiber has been used to make the composite with the closed mold hand lay- up process. The hand lay-up process consist of two mold plate in which lower mold plate having the mold cavity and the upper mold plate is to cover the mold cavity of the lower mold plate. The plastic sheet is applied in lower mold plate which works as the mold releasing agent in the process. Then after that the epoxy resin with the fibers are applied over it and again a plastic sheet is applied to cover it. Then the upper mold plate is applied over it and pressure of approximately 25 kg is applied on the upper mold plate and leaves it as it is for 24hours. Then after 24hours we get the composite sheet of epoxy resin with the fibers.

Fig 3.7 Setup for Closed hand lay-up.

The different types of composites which have been fabricated are shown in Fig.3.8

Fig 3.8 Fabricated composites of nettle fiber, woven glass fiber, random glass fiber.

3.3.2 Experimental Procedure

The formability analysis of polymer matrix composite sheets experimentally carried out with the procedure of drawing. Formability of polymer matrix composites sheet upon design and processing parameters like bend radius, die corner radius, punch shape, thickness of blank, different polymer matrix, different fiber in composites. The drawing experiment has been done for different punch shape, thickness of blank, different polymer matrix, different fibers in composites to see the effect of these parameters on formability of polymer matrix composite. The drawing process for formability analysis of polymer matrix composite is:

3.3.2.1 Drawing

Drawing could be a flat solid forming method during which a flat solid blank is radically drawn into a forming die by the mechanical action of a punch. It's therefore a form transformation method with material retention. The method is taken in to account "deep" drawing once the depth of the drawn half exceeds its diameter. This is often achieved by redrawing the half through a series of dies. The projection region (sheet metal within the die shoulder area) experiences a radial drawing stress and a tangential compressive stress as a result of the fabric retention property. These compressive stresses (hoop stresses) lead to projection wrinkles (wrinkles of the primary order). Wrinkles can be prevented by employing a blank holder, the operate of that is to facilitate controlled material flow into the die radius.

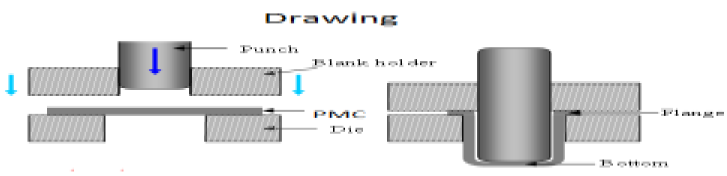


Fig. 3.9 Process of drawing.

Typical stages of a drawing process are as: a) Blanks are shear in the round rectangular or other shape. b) The blank is clamp on the die. c) Blank is stretched by the force of punch into die cavity. d) Punch is return and the part is remove from the die. e) Excess blank is trim.

3.3.3 Parameters used in Composite Drawing Process

3.3.3.1 Punch Shape

Composite sheets are drawn with the help of two different punches which are different in shape. The one punch is in round shape and the other is in spherical shape but the diameter of the both of the punch from is same which is 21mm.The experiment is carried out with both of the punch on the composite sheets with the different feed rate.

Fig3.10 Chamfer shaped tool and Spherical shaped tool.

3.3.3.2 Thickness of Sheets

Influence of different thickness of polymer matrix composite has been investigated by forming composite sheets. Sheets are with the different thickness .The corresponding thickness on which the experiments are carried out are of 1mm, 2mm and 3mm.The experiments for forming are carried out on the different thickness of polymer matrix composite sheets which are made with the composite molding machine.

3.3.3.3 Polymer Matrix

The different polymer matrix is used to make the composite sheets. The polymer matrix which is used to make the composite has great influence on the forming of the composite sheets. The two type of polymer matrix are used to make the composite sheets which are: Thermoplastic: Polypropylene, Polyethylene Thermoset: Epoxy The above polymer matrixes are used to make the composite sheets and experiments are carried out on the composite sheets.

3.3.3.4 Fiber Material:

For the drawing process of thermoplastic and thermosetting based composites three different types of fibers have been used are Nettle fiber, Woven glass fiber, Random glass fiber.3.4. Setup

Main Machine used: Drilling machine

Additional devices: Dynamometer; Amplifier; Digital Displacement indicator with probe; Computer device setup for software computing and evaluation of results

Fig 3.11 Experimental set up for drawing.

3.4.1 Dynamometer

The dynamometer is also called the "dyno" for short, which is a device for measuring toque, force. For example it can measure the power which is produced by an engine or motor

KISTLER 9272 dynamometer is used for experiment. It is a 4-element for measuring instrument to find torque and force. Four component measuring device for menstruation a torque Mz and therefore the orthogonal components of a force which are three in number. The device encompasses a nice rigidity and consequently a high natural frequency. Its high resolution permits the littlest dynamic changes in giant forces and torques to be measured.

3.4.1.1 Description:

The dynamometer consists of a four sensing element fitted below high preload between a base plate and a prime plate. The four elements are measured much while not displacement. It should be taken into consideration that combined and eccentric loads cut back the measuring ranges. The sensing element is mounted ground-isolated. So mischance issues are for the most part eliminated. The measuring device is rust proofed and guarded against penetration of splash water and cooling agents. Beside the connecting cable kind 1677A5/1679A5 it corresponds to the protection category IP67.

3.4.1.2 Technical Data:

Measuring range	F_x, F_y	kN	–5 ... 5 [1)]
	F_z	kN	–5 ... 20 [2)]
	M_z	N·m	–200 ... 200
Calibrated measuring range			
100 %	F_x, F_y	kN	0 ... 5
	F_z	kN	0 ... 20
	M_z	N·m	0 ... 200
			0 ... –200
10 %	F_x, F_y	kN	0 ... 0,5
	F_z	kN	0 ... 2
	M_z	N·m	0 ... 20
			0 ... –20
Overload	F_x, F_y	kN	–6/6
	F_z	kN	–6/24
	M_z	N·m	–240/240
Max. bending moment	M_x, M_y	N·m	–400 ... 400
Threshold	F_x, F_y	N	<0,01
	F_z	N	<0,02
	M_z	mN·m	<0,2
Sensitivity	F_x, F_y	pC/N	≈–7,8
	F_z	pC/N	≈–3,5
	M_z	pC/N·m	≈–160

Fig 3.12 Technical data of dynamometer.

3.4.2 Amplifier

4-Channel Charge Amplifier of type 5070Ax01xxis used with dynamometer KISTLER 9272. The 4-Channel Charge Amplifier is connected with dynamometer with the help of a multi-core high-insulation connecting cable. Charge signals are converted from the dynamometer into output voltages. The forces and moments are proportional to the output voltage.

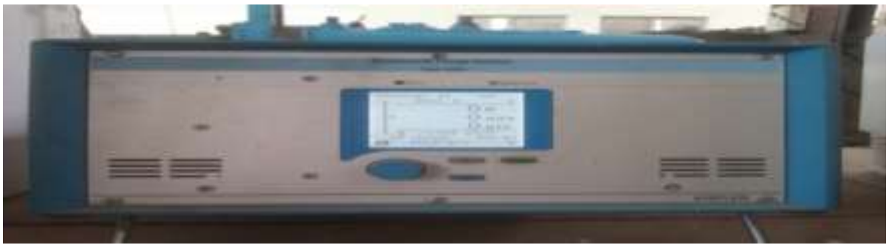


Fig 3.13 Channel Charge Amplifier of type 5070

3.4.3 Digital Displacement Indicator With Probe:

Digital displacement indicator is used to get the displacement of the drawing tools. The displacement indicators also have the metallic probe attached with it showing the displacement of the tool.

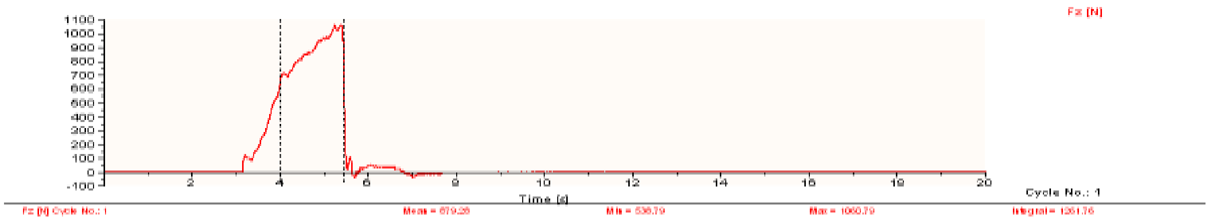


Fig.3.14 Variation of applied load with respect to time.

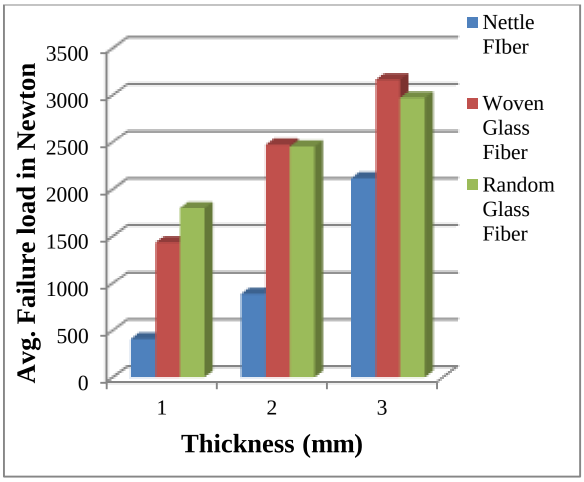
As can be seen in the Fig.3.14 the force applied starts to increase at t = 3 sec, and increases with respect to time till t=5.5 sec after which it falls down to zero. This point represents the point of breakage of the fiber composite. The Average failure load has been calculated between the time span between t=4 sec to t=5.5 seconds.

Result

4.1 Average failure load with respect to varying thickness with chamfered shaped tool.

4.1.1 Average Failure Load With Respect to Varying Thickness for 5 Seconds With Chamfered Shaped Tool:

The failure load at varying thickness of all types of fabricated composites (polypropylene, polyethylene and epoxy based) was recorded. The values have been plotted figure 4.1, figure 4.2, figure 4.3 from the result it was found that the average failure load of woven glass fiber composite among all three type of composites have better values as compared to random glass fiber and nettle fiber based composite at varying thickness as the thickness increases, the average failure load increases. But in the case of nettle fiber based composites, although the values are increasing as the thickness increases, when overall failure load is compared with other composites the failure load is less always. The values of random glass based composites are intermediate at all the thicknesses. Therefore it is clear from the results that woven glass fiber based composites fabricated with epoxy are promising when compared to other two types; nettle and random glass fiber based composites.



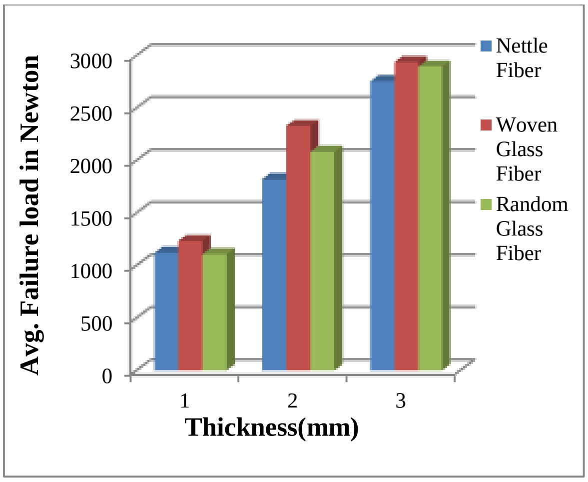


Fig4.1 average failure load for different types of epoxy based composites (Chamfered tool).

Fig4.2 Average failure load for different types of polypropylene based composites (Chamfered tool).

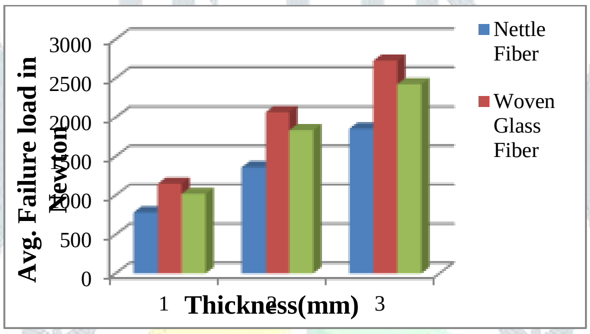
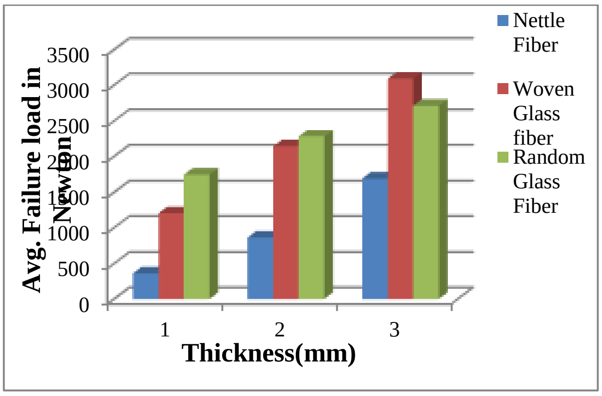


Fig4.3 Average failure load for different types of polyethylene based composites (Chamfered tool).

4.1.2 Average Failure Load With Respect to Varying Thickness for 10 seconds With Chamfered Shaped Tool

The failure load at varying thickness of all types of fabricated composites (polypropylene, polyethylene and epoxy based) was recorded. The values have been plotted figure 4.4, figure 4.5, figure 4.6 from the result it was found that the average failure load of woven glass fiber composite among all three type of composites have better values as compared to random glass fiber and nettle fiber based composite at varying thickness as the thickness increases, the average failure load increases. But in the case of nettle fiber based composites, although the values are increasing as the thickness increases, when overall failure load is compared with other composites the failure load is less always. The values of random glass based composites are intermediate at all the thicknesses. But when the chamfered shaped tool is used for 10 seconds the average failure load comes less as compare to average failure load when tool is applied for 5 seconds. Therefore it is clear from the results that woven fiber based composites fabricated with polypropylene is more when compared to other two types of nettle and random glass fiber based composites.



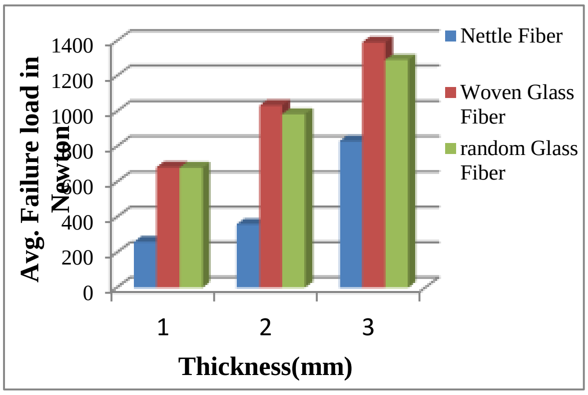


Fig4.4 average failure load for different type of epoxy based composites (Chamfered tool).

Fig 4.5 Average failure load for different type of polypropylene based composites (Chamfered tool).

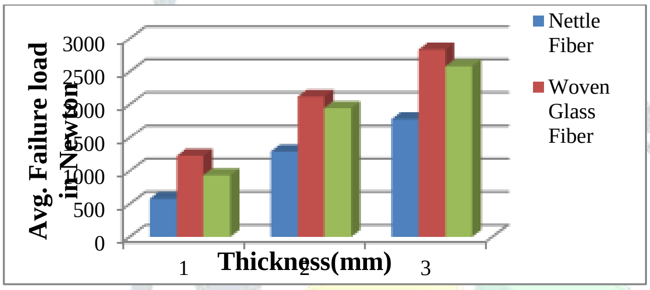
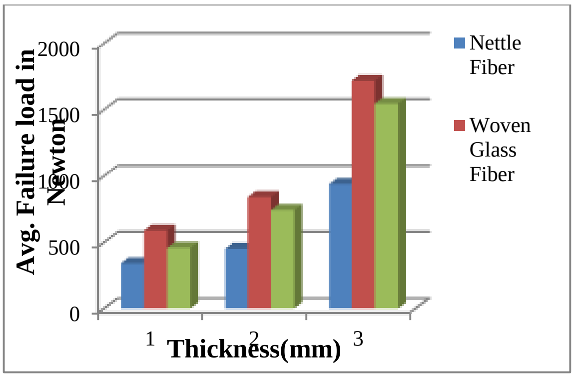


Fig 4.6 Average failure load for different types Polyethylene based composites.

4.2 Average failure load with respect to varying thickness with spherical shaped tool

4.2.1 Average Failure Load With Respect to Varying Thickness for 5 Seconds With Spherical Shaped Tool

The failure load at varying thickness of all types of fabricated composites (polypropylene, polyethylene and epoxy based) was recorded. The values have been plotted in figure 4.7, figure 4.8, figure 4.9 From results it was found that average failure load is almost half as compared to the chamfered shaped tool and the average failure load of woven glass fiber composite among all three type of composites have better values as compare to random glass fiber and nettle fiber based composite at varying thickness as the thickness increases, average failure load increases. But in the case of nettle fiber based composites, although the values are increasing as the thickness increases, when overall failure load is compared with other composites the failure load is less always. The values of random glass based composites are intermediate at all the thicknesses. But when the spherical shaped tool is used then the average failure load for all fiber composite reinforced with epoxy, polyethylene and polypropylene comes less as compared to the average failure load of chamfered shaped tool.



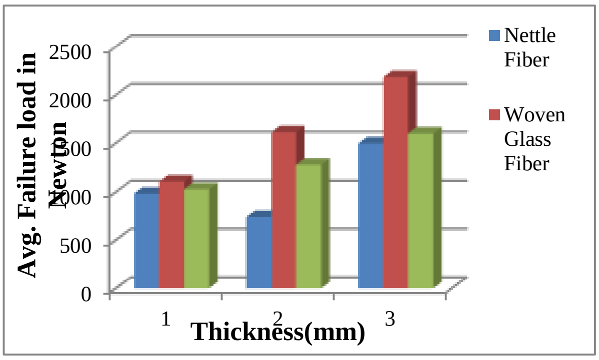


Fig.4.7 average failure load for different type of polypropylene based composites (Spherical tool).

Fig.4.8 Average failure load for different type Epoxy based composites (Spherical tool).

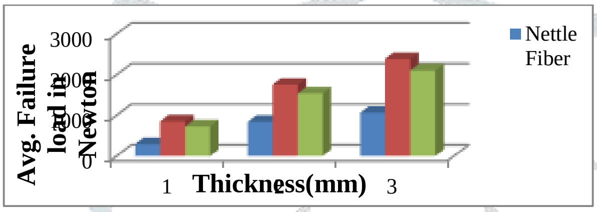


Fig4.9 Average failure load for different types of polyethylene based composites (Spherical tool).

4.2.2 Average Failure Load With Respect to Varying Thickness for 10 Seconds With Spherical Shaped Tool

The failure load at varying thickness of all types of fabricated composites (polypropylene, polyethylene and epoxy based) was recorded. The values have been plotted figure 4.10, figure 4.11, figure 4.12 from the result it was found that the average failure load is almost half as compared to the chamfered shaped tool but when tool is applied for 5 seconds the average failure load little bit increases as compared when tool is applied for 10 seconds.

From the result it was found that the average failure load of woven glass fiber composite in all three type of composites have better values when compare to random glass fiber and nettle fiber based composite at varying thickness as the load increase as thickness increases. But in the case of nettle fiber based composites, although the values are increasing as the thickness increases, though, when overall failure load is compared with other composites the failure load is less always. And the values of random glass based composites are intermediate at all the thicknesses. But when the spherical shaped tool is used then the average failure load for all fiber composite fabricated with the epoxy, polypropylene, polyethylene comes less as compared to the average failure load of the chamfered shaped tool.

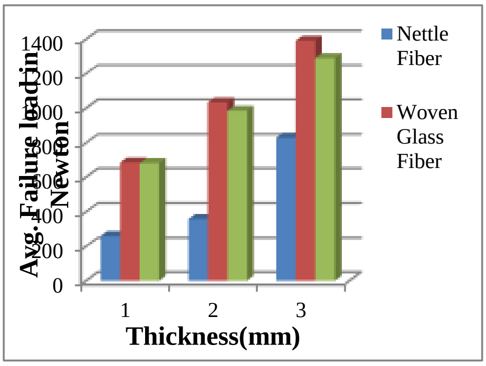


Fig 4.10 Average failure load for different type of epoxy based composites (Spherical tool).

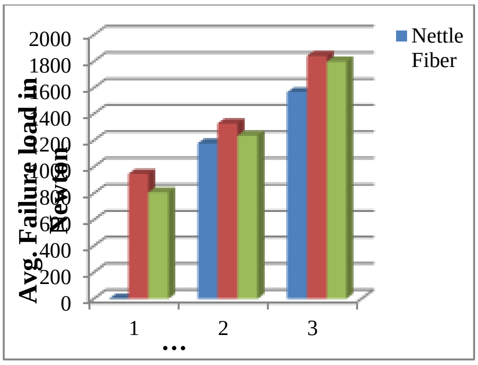


Fig 4.11 Average failure load for different type of polypropylene based composites (Spherical tool).

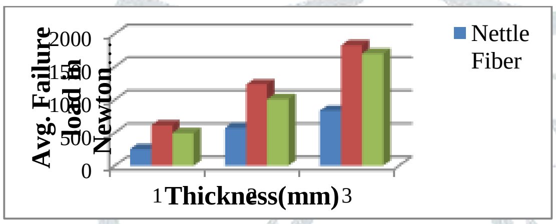


Fig. 4.12 Average failure load for different types of polyethylene based composites (Spherical tool).

4.3 Drawing limit with respect to varying thickness of composites with polypropylene and polyethylene with chamfered shaped tool

The drawing limit at varying thickness of all types of fabricated composites (polypropylene, polyethylene and epoxy based) was measured. From the observation, it was found that the drawing limit of the composite of woven glass fiber with polypropylene and polyethylene is maximum which is 3mm as compared to the composites of nettle fiber and random glass fiber.

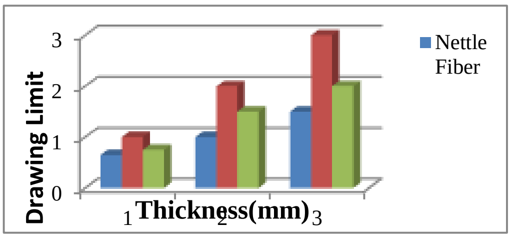


Fig 4.13 Drawing limit of nettle fiber, woven random glass fiber composites (Chamfered tool).

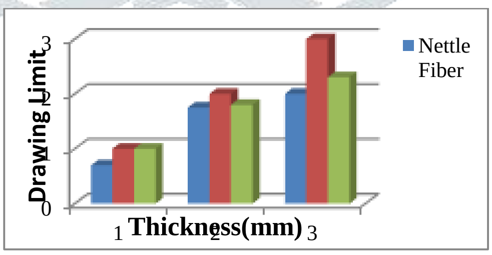


Fig.4.14 Drawing limit of nettle fiber, woven glass fiber, glass fiber random glass fiber composite with with polypropylene polyethylene (Chamfered tool).

4.4 Drawing limit with respect to varying thickness of composites with polypropylene and polyethylene with spherical shaped tool

The drawing limit at varying thickness of all types of fabricated composites (polypropylene, polyethylene and epoxy based) was measured. From the observation, it was found that the drawing limit of the composite of woven glass fiber with polypropylene matrix is 4.5 mm and polyethylene is 6mm as compared to the composites of nettle fiber and random glass fiber**.**

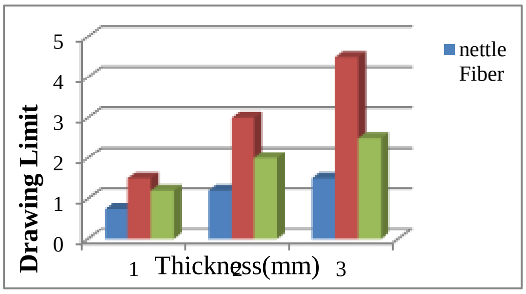


Fig 4.15 Drawing limit of nettle fiber, random glass fiber composites with polypropylene (Spherical tool).

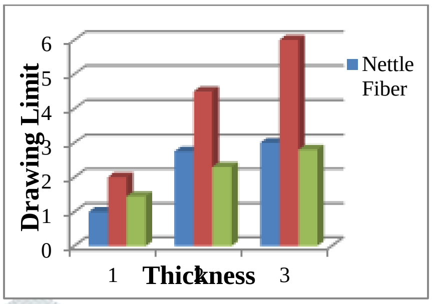


Fig 4.16 Drawing limit of nettle fiber, woven fiber, glass , woven glass fiber, random glass fiber Composite with polyethylene (spherical tool).

Conclusion and Future Scope

Conclusion

In the present research work various types of composites have been fabricated using different polymer matrices; polypropylene, polyethylene, and epoxy with natural fibers and synthetic fibers. After fabricating the composites, the forming operation was performed. Two types of tools, chamfered and spherical shaped are investigated. The average failure load and the drawing limit were measured. The following conclusion can be drawn on the basis of the present work: The failure load of woven glass fiber reinforced composite at varying thickness viz. 1mm, 2mm, 3mm in 5 seconds and 10 seconds have far better load carrying capacity in comparison to the random glass fiber and nettle fiber with all type of used matrices based composites with the chamfered tool. When average failure load is recorded for 5 and 10 seconds of time, it was observed that the load is almost half of 5 seconds when compared to 10 seconds, when the spherical shaped tool is used. Nettle fiber based composites take lowest load to failure as compared to the other types of composites. Random glass fiber based composites have intermediate failure load capacity. The spherical tool led to an early failure in the composites, as compared to the chamfered tool. Drawing of composites with the spherical shaped tool having better drawability as compared to composite formed with the chamfered shaped tool. In the drawability, woven glass fiber based composites have good drawability as compared to other two type of composites investigated. It can also be concluded that composites of all the fibers with thermoset (epoxy) cannot be drawn. From the result it was found that when the chamfer and spherical shaped tools are employed on the epoxy based composites they fractured. Hence, it can be concluded that woven glass fiber based composites in all types matrices have far better load bearing capacity at all thicknesses (1mm, 2mm, 3mm) and much better drawability in thermoplastic (polypropylene and polyethylene) based composites.

Future scope

In the present study, nettle fiber, woven glass fiber, random glass fibers are used to make the composite sheets with thermoplastic and thermoset matrices. The drawing has been done without heating the composite sheets. Therefore the analysis can be done for formability of composites after heating the sheets. Effect of processing and design parameters can be analyzed on the all natural fibers like hemp fiber, sisal fiber, jute fiber etc. with matrices of thermoplastic and thermosetting matrices.

References

[1] N. Srinivasababu, K. Murali Mohan Rao, J Suresh Kumar, "Experimental determination of tensile properties of okra, sisal and banana fiber reinforced polyester composites" *Indian Journal of Science and Technology,* 2 No. 7 (July 2009) ISSN: 0974- 6846.

[2] Debabrata Debnath "Mechanical behavior of bagasse fiber epoxy composites at liquid nitrogen temperature" *Thesis- NIT Rourkela.*

[3] Mohd. Yusoff, Mohd. Zuhri, Mohd. Sapuan Salit, Napsiah Ismail, Riza Wirawan "Mechanical properties of short random oil palm fibre reinforced epoxy composites" *Sains Malalaysiana*, 39(1) (2010) 87-92.

[4] Sewench N. Rafeeq, Inaam M. Abdulmajeed, Areej Riyadh Saeed, "Mechanical and thermal properties of date palm fiber and coconut shell particulate filler reinforced epoxy composite" *Indian Journal of Applied Research, 3* (2013) Issue : 4.

[5] Beckry Abdel-Magid, Saeed Ziaee, Katrina Gass, Marcus Schneider "The combined effects of load, moisture and temperature on the properties of E-glass/epoxy composites" *Composite Structures*, 71 (2005) 320-326.

[6] Hasim Pihtili, "An experimental investigation of wear of glass fibre-epoxy resin and glass fibre-polyester resin composite materials" *European Polymer Journal,* 45 (2009) 149-154.

[7] V. Lopresto, C. Leone, I. De Iorio, "Mechanical characterisation of basalt fibre reinforced plastic" *Composites: Part B,* 42 (2011) 717-723.

[8] CS. Varga, N. Miskolczi, L. Bartha, G. Lipoczi "Improving the mechanical properties of glass-fibre-reinforced polyester composites by modification of fibre surface" *Materials and Design,* 31 (2010) 185-193.

[9] Han Song Hee, Hyun Ju Oh, Hyun Chul Lee, Seong Su Kim, "The effect of post-processing of carbon fibers on the mechanical properties of epoxy-based composites" *Composites: Part B,* 45 (2013) 172-177.

[10] Yu Dong , Arvinder Ghataura , Hitoshi Takagi , Hazim J. Haroosh , Antonio N. Nakagaito, Kin-Tak Lau "Polylactic acid (PLA) biocomposites reinforced with coir fibres" *Journal of Composite Materials,* 63 (2014) 76–84.

[11] Oksman K, Skrifvars M and Selin JF. Natural fibers as reinforcement in poly lactic acid (PLA) composites. *Compos Sci Technol*, 63 (2003) 1317-1324.

[12] Shih YF, Huang CC and Chen PW. Biodegradable green composites reinforced by the fiber recycling from disposable chopsticks. *Material Science Engineering,* 527 (2010) 1516-1521.

[13] Pramendra Kumar Bajpai, Inderdeep Singh and Jitendra Madaan, "Development and characterization of PLA-based green composites: A review" *Journal of Thermoplastic Material*, 101.177 (2012) 1-30.

[14] Shinichi Shibata, Rahman M. Bozlur, Isao Fukumoto, Yasuyuki Kanda, "Properties of Bagasse/ polypropylene Injection Molding composites" *Peer Reviewed Article Biosource*, 5 (2010) 2097-2111.

[15] Andrzej K. Bledzki and Omar Faruk, "Wood Fiber Reinforced Polypropylene Composites: Compression and Injection Molding Process", *Polymer-Plastic Technology and Engineering*, 43 (2004) pp. 871-888.

[16] H.M. Akil, M.F. Omar, A.A.M. Mazuki, S. Sallee, Z.A.M. Ishak, A. Abu Bakar, "Kenaf fiber reinforced composites: A review" *Materials and Design, 32* (2011) 4107-4121.

[17] Murtuza Ali Syed and Akheel Ahmed Syed, "Development of a new inexpensive green thermoplastic composite and evaluation of its physico-mechanical and wear properties" *Materials and Design*, 36 (2012) 421-427.

[18] Farkhondeh Hemmati and Hamid Garmabi, "A study on fire retardancy and durabilityperformance of Bagasse fiber/polypropylene composite for outdoor applications", *Journal of Thermoplastic Composite Materials*, 26 (2013) 1041.

[19] Ochi S., "Mechanical properties of kenaf fibers and kenaf/PLA composites". *Journal of Mechanical Materials*, 40 (2008) 446-52.

[20] Moyeenuddin A. Sawpan, Kim L. Pickering, Alan Fernyhough, "Flexural properties of hemp fibre reinforced polylactide and unsaturated Polyester composites", *Composites*: Part A, 43 (2012) 519-526.

[21] Andrzej K. Bledzki, Omar Faruk, Klaus Specht, "Influence of Separation and Processing Systems on Morphology and Mechanical Properties of Hemp and Wood Fibre Reinforced Polypropylene Composites" *Journal of Natural Fibers*, 4(3) (2007) 37-56.

[22] Samia Sultana Mir , Nazia Nafsin , Mahbub Hasan , Najib Hasan , Azman Hassan "Improvement of physico-mechanical properties of coir-polypropylene biocomposites by fiber chemical treatment" *Journal of Materials and Science*, 52 (2013) 251–257.

[23] J. Aurrekoetxea, M.A. Sarrionandia, I. Urrutibeascoa, M.L. Maspoch "Effects of injection moulding induced morphology on the fracture behaviour of virgin and recycled polypropylene" *Journal of Polymer*, 44 (2003) 6959–6964.

[24] Han-Seung Yang, Hyun-Joong Kim, Hee-Jun Park, Bum-Jae Lee, Taek-Sung Hwang "Effect of compatibilizing agents on rice-husk flour reinforced polypropylene composites" *Journal of Composite Structures*, 77 (2007) 45–55.

[25] J. Rout, M. Misra, S.S. Tripathy, S.K. Nayak, A.K. Mohanty "The influence of fibre treatment on the performance of coir-polyester composites" *Journal of Composites Science and Technology*, 61 (2001) 1303–1310.

[26] Takeshi Moriwaki "Mechanical property enhancement of glass fibre-reinforced polyamide composite made by direct injection molding process" *Composites*: Part A, 21 (1996) 379-384.

[27] J.L. Thomason, "The influence of fibre length and concentration on the properties of glass fibre reinforced polypropylene: Injection molded long and short fibre PP" *Composites*: Part A, 33 (2002) 1641-1652.

[28] R. A. Sousa, R. L. Reis, A. M. Cunha and M. J. Bevis, "Integrated compounding and injection molding of short fibre reinforced composites" *Plastics, Rubbers and Composites*, 33 (2004) 746-760.