CHAPTER 3

MATERIALS AND METHODS

This chapter describes the materials and methods used in this investigation. The equipments used for characterizing the properties of fibers and their composites are listed in Table 3.1.

Table 3.1 Equipments used for characterizing fibers and their composites

<table>
<thead>
<tr>
<th>Name of the Instruments</th>
<th>Specification</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fourier Transform Infrared Spectroscopy</td>
<td>Range : 400-4000 cm⁻¹ Accuracy: ± 0.01 cm⁻¹</td>
<td>To study the chemical structure of fibers</td>
</tr>
<tr>
<td>Thermo Gravimetric Analyzer</td>
<td>Range : 20°C to 1000°C Accuracy: ± 1°C</td>
<td>To study the thermal stability of fibers</td>
</tr>
<tr>
<td>Rapid I Machine Vision System</td>
<td>Range : 11 X to 134 X (Magnification)</td>
<td>To ascertain the cross – section area of fibers</td>
</tr>
<tr>
<td>X-Ray Diffraction Analysis</td>
<td>Range : -6° to 82° theta Accuracy : 0.001° theta</td>
<td>To study the percentage crystallinity of fibers</td>
</tr>
<tr>
<td>Single Filament Testing Machine</td>
<td>Capacity : 0.250 kN Accuracy : ± 0.5 % of applied load</td>
<td>To study the tensile properties of fibers</td>
</tr>
<tr>
<td>Universal Testing Machine</td>
<td>Measurement range of 2% to 100% with ± 0.5% accuracy of applied load</td>
<td>To determine the tensile and flexural strength of the composites</td>
</tr>
<tr>
<td>Impact Testing Machine</td>
<td>Blow range : 2 J to 25 J Impact velocity : 3.4 m/s</td>
<td>To determine the impact strength of composites</td>
</tr>
</tbody>
</table>
The experimental work involved in this investigation was segmented into five stages. The first stage of experimental work deals with the extraction and characterization of Dharbai and Christmas palm fibers. The second stage deals with composite fabrication and evaluation of mechanical properties of Dharbai - polyester and Christmas palm - polyester composites. The third stage of experimentation, aimed at studying the effect of fiber pretreatment on the mechanical behaviors of the composites. The fourth stage of experimental work attempted to characterize the alkalized Dharbai and Christmas palm fibers which offered better mechanical properties to their composites. The final stage of experimental work deals with regression modeling and optimization of the mechanical properties of alkali treated Dharbai - polyester and Christmas palm - polyester composites.

3.1 MATERIALS

3.1.1 Natural Fibers

The use of natural fiber reinforced polymer composites in engineering application is increasing rapidly. Exploration of new plants for its fiber can accelerate the substitution of synthetic fibers by natural fibers. Therefore, two new varieties of plant fibers namely, Dharbai and Christmas palm were selected as reinforcement materials for polyester matrix composites.

3.1.1.1 Dharbai fibers

The Dharbai fibers used in this investigation were extracted from the Dharbai plants. The Dharbai (Eragrostis Cynosuroides) plants are widely cultivated in both southern and northern parts of India. Since these plants do not require much water for higher yield, it could be cultivated in abundance and used for commercial applications.
3.1.1.2 Christmas palm fibers

*Adonidia merrillii* popularly known as Christmas palm is a native of the Philippines, cultivated in India. *Adonidia* is a monotypic genus of flowering plants from Arecaceae family. These palms are fairly small, slender and normally attain a height of 15–25 ft. Its fibers have been explored in this investigation and found to be a potential reinforcement for polyester matrix composites.

3.1.2 Unsaturated Polyester Resin

Polyester resins are unsaturated resins formed by the reaction between dibasic organic acids and polyhydric alcohols. General purpose unsaturated polyester resin (specific gravity @ 27°C: 1.136, viscosity: 470 cPs and mass per unit area: 449.96 g/m²) supplied by GRP Enterprises, Madurai, Tamil Nadu, India was used as the matrix material. Favorable factors such as low cost, availability and ease of curing at room temperature has provoked the use of polyester as matrix material. The resin system consist of polyester resin, Cobalt Octoate (accelerator) and Methyl Ethyl Ketone Peroxide (catalyst) mixed in the ratio of 1:0.015:0.015 by weight. The addition of catalyst and accelerator in the resin system leads to the formation of infinite molecular network through cross linking of polymers and offers rigid structure to the resin system.

3.1.3 Other Chemicals

Sodium hydroxide and potassium hydroxide chemicals in pellet form were used for the alkali treatment of Dharbai and Christmas palm fibers. The compositions of NaOH and KOH pellets used in this investigation are listed in Table 3.2 and the term assay represents the percentage purity of sodium hydroxide and potassium hydroxide pellets. Distilled water was used
for the preparation of alkali aqueous solution and dilute hydrochloric acid was used for rinsing treated fibers.

Table 3.2 Composition of NaOH and KOH pellets

<table>
<thead>
<tr>
<th>Sl.No.</th>
<th>Compositions</th>
<th>NaOH</th>
<th>KOH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Assay</td>
<td>97% min.</td>
<td>85% min.</td>
</tr>
<tr>
<td>2</td>
<td>Carbonate (Na₂CO₃/ K₂CO₃)</td>
<td>2.0% min.</td>
<td>2.0% min.</td>
</tr>
<tr>
<td>3</td>
<td>Sulphate (SO₄)</td>
<td>0.05% max.</td>
<td>0.002% max.</td>
</tr>
<tr>
<td>4</td>
<td>Lead (Pb)</td>
<td>0.001% max.</td>
<td>0.001% max.</td>
</tr>
<tr>
<td>5</td>
<td>Chloride (Cl)</td>
<td>0.01% max.</td>
<td>0.003% max.</td>
</tr>
<tr>
<td>6</td>
<td>Silicate (SiO₂)</td>
<td>0.05% max.</td>
<td>0.01% max.</td>
</tr>
<tr>
<td>7</td>
<td>Iron(Fe)</td>
<td>0.001% max.</td>
<td>0.004% max.</td>
</tr>
<tr>
<td>8</td>
<td>Potassium (K)</td>
<td>0.1% max.</td>
<td>-</td>
</tr>
<tr>
<td>9</td>
<td>Sodium (Na)</td>
<td>-</td>
<td>0.5% max.</td>
</tr>
</tbody>
</table>

3.2 EXTRACTION AND CHARACTERIZATION OF FIBERS

3.2.1 Fiber Extraction

3.2.1.1 Extraction of Dharbai fiber

The Dharbai leaves are chopped off with the knife and dried in the shade for three days. The resultant fibers were water retted for 8 days and rinsed with water for removing the foreign impurities formed during retting process. The fibers were then dried at a room temperature for 2 days to remove the moisture content from the fiber. Figure 3.1 illustrates the extraction process of Dharbai fibers.
3.2.1.2 Extraction of Christmas palm fiber

The source of Christmas palm fiber is the foliage of the Christmas palm tree, which falls onto the ground as it ripens. The sheath collected was immersed in a water-retting tank for 15 days to segregate fibers from the sheath. The fibers were cleaned by means of water rinsing and dried at room temperature for 3 days to remove the moisture content. The gums present in the sheath dissolved in water completely and excess hard impurities present over the surface of the fiber were removed by combing process. The procedure followed for extracting Christmas palm fibers from its sheath is shown in Figure 3.2.
3.2.2 Characterization of Fibers

3.2.2.1 Chemical analysis

The chemical compositions of Dharbai and Christmas palm fibers were determined by means of chemical analysis. The grounded test sample of weight 0.5 g was hydrolyzed with 5 mL of 72% w/w sulfuric acid and the suspension left after hydrolysis were dried and weighted as $W_1$. The dried sample was ignited in a muffle furnace at 525°C and the residue was weighted as $W_2$ (ash content). The acid insoluble lignin present in the sample was ascertained by calculating the difference between $W_1$ and $W_2$. The glucose and reduced sugar concentrations in the filtrate (obtained from $\text{H}_2\text{SO}_4$ treatment) were estimated as per glucose oxidase - peroxidase assay kit and DNS method (Miller 1959) respectively. The concentration levels of glucose
and reduced sugar was used to calculate the percentage composition of cellulose and hemicellulose in the fibers (Ververis et at 2007).

The percentage moisture content in Dharbai and Christmas palm fibers were determined as per TAPPI 258 om-11 standard. The test sample was dried at a temperature of 105°C and the difference in weight before and after drying was used to estimate the moisture content in the sample. The functional group and chemical structure of Dharbai and Christmas palm fibers were determined using Fourier Transform Infrared (FTIR) spectroscopy.

3.2.2.2 Thermo-gravimetric analysis

Thermo Gravimetric Analysis (TGA) technique uses heat, to drive the physical changes in materials and provides quantitative measurement of mass change in the materials, associated with a transition or thermal degradation. The thermal degradation of Dharbai and Christmas palm fibers were studied using thermo gravimetric analyzer. The thermal stability of newly introduced fibers was compared with natural fibers such as sisal, banana and coir fibers which have been already reported as possible reinforcement materials for polymer matrix composites.

![Photographic image of thermo gravimetric analyzer](image)

Figure 3.3 Photographic image of thermo gravimetric analyzer
Figure 3.3 shows the photographic image of thermo gravimetric analyzer. The sample analysis was carried out using a Perkin Elmer - 4000 analyzer, operated in a dynamic mode with a heating scheme ranging from 30°C to 800°C at a heating rate of 10°C/min, in a nitrogen environment purged at 20 ml/min. The change in mass due to decomposition, oxidation or degradation of the sample with respect to time and temperature was recorded and plotted with the help of data logging system interfaced with the TGA.

3.2.2.3 Density measurement

Pycnometric procedure was followed to measure the density of natural fibers (Beakou et al 2008). Toluene of density ($\rho_t$): 866 kg/m$^3$ was employed as the immersion liquid and the formula used to calculate the density of fibers is given in the Equation (3.1).

$$\rho_f = \frac{(m_2 - m_4)}{(m_3 - m_1) - (m_4 - m_2)} \rho_t$$  \hspace{1cm} (3.1)

Where $\rho_f$ is the density of the fiber (kg/m$^3$), $\rho_t$ is the density of the toluene (kg/m$^3$), $m_1$ is the mass of the empty pycnometer (kg), $m_2$ is the mass of the pycnometer filled with chopped fibers (kg), $m_3$ is the mass of the pycnometer filled with toluene (kg) and $m_4$ is the mass of the pycnometer filled with fibers and toluene (kg). Figure 3.4 shows the photographic image of pycnometer.
3.2.2.4 Diameter measurement

The diameter of the fibers was measured with the help of Rapid-I machine vision inspection system as shown in Figure 3.5. The Rapid-I software was used to measure the fiber diameter; the lighting control in the software was utilized to illuminate the sample to be inspected. The coarse/fine adjustment knob was used to bring the component under the camera and magnification was adjusted to the desired setting. Appropriate cross-hair type and geometric entities were selected to measure the fiber diameter. Ten samples were examined for each type of fiber and the average value was recorded.

![Figure 3.5 Photographic image of Rapid-I Machine Vision System](image)

3.2.2.5 Single filament test

The extracted Dharbai and Christmas palm fibers were subjected to single filament test for evaluating their tensile properties. The monofilament of each fiber was tested using the Instron (Model: 5500 R) testing machine at the loading rate of 5 mm/min until the fiber fractures at 21 ± 1°C temperature.
and at 55 ± 2 % RH. The test was carried out as per ASTM D 2256 standard. To obtain a statistically significant result, twenty filaments were tested from each type of fibers and the average value of tensile strength and tensile elongation was reported. The photographic image of single filament testing machine is shown in Figure 3.6.

![Photographic image of Single filament testing machine](image)

**Figure 3.6 Photographic image of Single filament testing machine**

### 3.3 COMPOSITE FABRICATION

Compression molding machine (Make: ACE, Model: 30 HBM) was used for the fabrication of randomly oriented Dharbai - polyester and Christmas palm - polyester composites (Malick 1993, Ramprasath et al 2014b). The composite sheets were prepared by varying the fiber weight content (5 % to 50 %) and fiber length (10, 30 and 50 mm) in the composites. The Dharbai and Christmas palm fibers were chopped to a required length and individually reinforced in the matrix system consisting of unsaturated polyester resin, Cobalt Octoate accelerator and MEKP catalyst mixed in the ratio of 1:0.015:0.015 by weight.
The prepreg was placed in the stainless steel mold of dimension 300 × 300 × 3 mm and compressed by the upper and lower jaws of the compression molding machine at a temperature of 60° C and at a pressure of 2.6 MPa for 45 min. The photographic image of compression molding machine and fabricated composite specimens are shown in Figure 3.7 and 3.8, respectively. After fabrication, the composite sheets were carefully removed from the mold and cured at room temperature. The cured specimens were cut to the required dimensions and subjected to tensile, flexural and impact test as per ASTM standards.

Figure 3.7 Photographic image of compression molding machine

Figure 3.8 Photographic image of mold and fabricated composites
3.4 MECHANICAL TESTING OF COMPOSITES

3.4.1 Tensile Test (ASTM D 638 - 08)

The tensile strength of neat polyester resin and the prepared composites were tested using a computerized universal testing machine (Model: UNITEK 94100, Max Capacity: 10 KN) as per ASTM D 638-08 standard. The samples were cut to approximate dimensions of 165 × 25 × 3 mm and tested at a cross-head speed of 5 mm/min at 24 ± 2°C and 50 ± 5% relative humidity (Figure 3.9). Five samples were tested for each set of conditions and the average value of tensile strength was reported. Figure 3.10 shows the photographic images of dog bone type, tensile fractured specimens.

Figure 3.9 Photographic image of tensile testing machine

Figure 3.10 Photographic images of tensile fractured specimens
3.4.2 **Flexural Test (ASTM D 790 – 07)**

Three-point bending test method (ASTM D 790 – 07) was used to determine the flexural strength of the composites. The length, width and thickness of each sample were approximately 125, 12.5 and 3 mm, respectively. The composite specimen of rectangular cross section was posited as a simply supported beam and the point load were applied in the middle of the specimen at the rate of 5 mm/min. at 24 ± 2°C and 50 ± 5% relative humidity as shown in Figure 3.11. The loading nose with cylindrical surface was used to avoid excessive indentation, or failure due to stress concentration directly under the loading nose. The composite specimens were deflected until the rupture occurs at the outer surface of the specimen.

![Figure 3.11 Photographic image of flexural testing machine](image)

The flexural strength of the composite was calculated using the Equation (3.2) given below:

\[
\text{Flexural Strength } (f_s) = \frac{3PL}{2bd^2} \quad (3.2)
\]
Where

- $P$ - Applied load (N)
- $L$ - Test span of the sample (mm)
- $b$ - Width of the specimen (mm)
- $d$ - Thickness of the specimen (mm)

Figure 3.12 shows the photographic images of flexural fractured specimens. To obtain a statistically significant result, five specimens were tested and average value of flexural strength was recorded.

![Photographic images of flexural fractured specimens](image)

**Figure 3.12 Photographic images of flexural fractured specimens**

### 3.4.3 Impact Test (ASTM D 256 – 07)

The fabricated composites were tested for its impact strength in accordance to ASTM D 256-07. The test was carried out using a pendulum type impact testing machine (Make: Tinius Olsen) as shown in Figure 3.13. Testing conditions of $23\pm2$ $^\circ$C temperature and relative humidity of $50 \pm5 \%$ were followed. The test specimen of dimensions $62.5 \times 12.5 \times 3$ mm was supported as a vertical cantilever beam and broken by a single swing of a pendulum. The pendulum strikes the face of the samples and total of five samples were tested for each conditions and the mean value of the absorbed energy was recorded. The Izod impact strength of the composites was
calculated using the Equation (3.3). The photographic image of impact fractured specimens is shown in Figure 3.14.

\[
\text{Impact strength (kJ/m}^2\text{)} = \frac{\text{Impact energy (J)}}{\text{Cross sectional area (m}^2\text{)}} \tag{3.3}
\]

Figure 3.13 Photographic image of impact testing machine

Figure 3.14 Photographic image of impact fractured specimens
3.5 ALKALI TREATMENT

The physical interlock between the natural fibers and matrix has got higher influence on the mechanical properties of the composites (Ray et al 2001). In order to enhance the interfacial bonding between the fibers and the matrix, Dharbai and Christmas palm fibers were subjected to surface treatment using the alkali aqueous solution. Alkali treatment offers rough surface topography to fibers and thus improves the physicochemical interaction between the fiber and matrix (Jahn et al 2002). Two types of alkali solution (sodium hydroxide and potassium hydroxide) were used for the chemical modification of fibers and their influence on the improvement of mechanical properties of the composites was comparatively analyzed.

The Dharbai and Christmas palm fibers were soaked in NaOH aqueous solutions of varying concentration (2%, 4%, 6%, 8% and 10%) for various time intervals (12, 24, 36, to 96 hours) as per full factorial design of experiments. Similarly, KOH aqueous solutions of varying concentration (2%, 4%, 6%, 8% and 10%) were prepared, and the fibers were soaked in the prepared solution for various periods of time (12, 24, 36, to 60 hours). After specific time intervals, the fibers were removed from the solution and rinsed with dilute hydrochloric acid in order to remove any excess NaOH/KOH sticking over the fiber surface. Finally the fibers were washed with the distilled water and dried at room temperature for 24 hours. The fibers alkalized at a wide range of treatment conditions were reinforced in the polyester matrix and four different types of composites were prepared as follow:

- NaOH treated Dharbai - polyester composites
- KOH treated Dharbai - polyester composites
- NaOH treated Christmas palm - polyester composites
- KOH treated Christmas palm - polyester composites
The mechanical proprieties of the fabricated composites were tested as per the procedures detailed in the section 3.4 and the effect of treatment parameters (solution concentration and soaking time) on the mechanical properties of the composites were ascertained.

### 3.6 SCANNING ELECTRON MICROSCOPY (SEM)

The fracture behavior of the composite specimens subjected to tensile, flexural and impact test was studied using a Hitachi S-3000N model Scanning Electron Microscope (SEM) operated at 20 kV. In order to enhance the electrical conductivity of the composites, the specimens were washed, dried and surface coated with gold before inspection. The scanning electron microscope images the specimen surface by scanning it with a high energy beam of electrons in a raster scan pattern. The obtained SEM images were used to study the physicochemical interaction between the untreated /treated fibers and the polyester matrix.

### 3.7 CHARACTERIZATION OF ALKALIZED FIBERS

The surface topography of NaOH and KOH treated fibers (Dharbai and Christmas palm) which favored the mechanical properties of the composites was characterized using Rapid-I machine vision system. Fourier transform infrared (FTIR) spectroscopy was employed to study the chemical structure of alkalized fibers. X-ray diffraction (XRD) technique was used to ascertain the effect of alkalization on the percentage crystallinity of fibers.

#### 3.7.1 Fourier Transform Infrared (FTIR) Spectroscopy

Fourier-transform infrared spectroscopy is a technique for identifying types of chemical bonds in a molecule by producing an infrared
absorption spectrum. The intensity of the absorption spectrum can be utilized to study the effect of alkali treatment on the chemical structure of natural fibers (Pavia et al 2008).

About 2 mg of untreated / treated fibers was crushed into small particles and mixed thoroughly with potassium bromide. The mixtures were compressed into a small disc of about 1-mm thick and exposed to the infrared spectrum. The infrared spectra of untreated, NaOH and KOH treated fibers (Dharbai and Christmas palm) which favored the mechanical properties of the composites were obtained over wave numbers ranging from 400 to 4000 cm\(^{-1}\) at a resolution of 4 cm\(^{-1}\) using a Perkin-Elmer FTIR Spectrometer.

3.7.2 X-Ray Diffraction Technique

The effect of alkali treatment parameters on the crystallinity of Dharbai and Christmas palm fibers was determined using X-ray diffraction technique. The untreated / treated fibers (which offered better mechanical properties to the composites) were mixed with small quantity of adhesive material, i.e. Tragacanth BP and compressed into thin sheets for investigation.

The investigation was carried out with Cu-K\(\alpha\) (1.5418 Å) radiation generated at 40 kV and 40 mA. The diffraction spectra analyzed in this study were collected from the 2\(\theta\) angle between 10\(^\circ\) and 80\(^\circ\) scanned at a speed of 0.05\(^\circ\) /s. The percentage crystallinity of untreated and treated fibers was computed using Equation (3.4) (Kaith et al 2003, Kaushik et al 2012).

\[
\text{% Crystallinity} = \frac{I_{002}}{I_{002} + I_{am}} \times 100 \tag{3.4}
\]

Where \(I_{002}\) and \(I_{am}\) are the crystalline and amorphous intensities at 2 \(\theta\) scale, respectively.
3.8 REGRESSION ANALYSIS

Regression analysis is a statistical technique that uses quantitative data from appropriate experiments to formulate the regression equation between the dependent and independent variables (Box & Draper 1987, Cornell 1990). Based on the experimental values obtained, regression models were developed to predict mechanical behaviors of alkalized Dharbai-polyester and Christmas palm-polyester composites over a wide range of treatment conditions.

The tensile strength (MPa), flexural strength (MPa) and impact strength (kJ/m$^2$) were considered as the process response ($y$), which is a function of the independent variables, namely, solution concentration ($s_c$) in % and soaking time ($s_t$) in hrs, which can be expressed as follow

$$y = e + f(s_c, s_t)$$ (3.5)

The term $e$ represents any measurement error in the response, as well as a statistical error that is assumed to distribute normally with zero mean and variance. The levels of the independent variables were converted into coded factors (Table 3.3) and second order polynomial equations were developed to predict the mechanical behaviors of the Dharbai-polyester and Christmas palm-polyester composites.

**Table 3.3 Input variables in terms of coded factors**

<table>
<thead>
<tr>
<th>Independent variables</th>
<th>Coded factors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-1</td>
</tr>
<tr>
<td>Solution concentration ($s_c$)</td>
<td>2</td>
</tr>
<tr>
<td>Soaking time ($s_t$)</td>
<td>12</td>
</tr>
</tbody>
</table>
Subsequently, two tailed ANOVA (Analysis of Variance) test was performed with 95% confidence level and the significance of each term on the developed models was ascertained. The fitness of predicted values and the experimental values obtained from mechanical testing of composites was checked using the statistical plots listed below

- **Normal Probability plot** was used to check the normal distribution of residual errors.
- **Scatter plot** was used to estimate the residual errors between predicted and experimental values.
- **Perturbation plot** was used to determine the influence of independent variables (solution concentration and soaking time) on the responses (tensile, flexural and impact strength).
- **3D surface plot** was used to illustrate the interaction effect of input variables on the responses.

### 3.9 PARTICLE SWARM OPTIMIZATION

Optimization technique determines the conditions best suited to a problem for a given circumstance. The use of heuristic optimization techniques can improve the performance of parameter estimation with less computational effort, when compared to that of conventional classical algorithms (Nagesh Kumar & Janga Reddy 2007). Particle Swarm optimization (PSO) was used in this investigation to optimize the mechanical performance of alkalized Dharbai - polyester and Christmas palm - polyester composites. PSO is a heuristic method of optimization based on the collective behavior of decentralized, self-organized swarm systems (Kennedy & Eberhart 1995, Jarboui et al 2008). In PSO, every particle flies through the multidimensional space and adjusts its position \((x_i^t)\) in every time step \(t\) with its own and swarm experiences, the position of each particle \(i\) updated in the search space can be represented as follows
\[ x_{i}^{t+1} = x_{i}^{t} + v_{i}^{t+1} \quad \text{with} \quad x_{i}^{0} \sim U(x_{\text{min}}, x_{\text{max}}) \] (3.6)

Where \( v_{i}^{t} \) is the velocity vector of particle that drives the optimization process and reflects both the own and social experience knowledge of all particles, \( U(x_{\text{min}}, x_{\text{max}}) \) is the uniform distribution where \( x_{\text{min}} \) and \( x_{\text{max}} \) are its minimum and maximum values respectively.

The global best PSO was followed in this investigation where the position of each particle is influenced by the best-fit particle in the entire swarm. The \( g_{\text{best}} \) PSO uses a star social network topology where the social information is obtained from all particles in the swarm. Each particle in the swarm keeps track on its coordinate in the search space and the personal best position \( (P_{\text{best},i}) \) corresponds to the position in search space where particle had the largest value as determined by the objective function. In addition, the position yielding the largest value among all the personal best \( (P_{\text{best},i}) \) is called the global best position \( (G_{\text{best},i}) \). The velocity of the particle \((i)\) is calculated by

\[ v_{ij}^{t+1} = v_{ij}^{t} + c_{1}r_{1}^{t}\left[ P_{\text{best},i}^{t} - x_{ij}^{t} \right] + c_{2}r_{2}^{t}\left[ G_{\text{best}} - x_{ij}^{t} \right] \] (3.7)

Where

\[ v_{ij}^{t} = \text{Velocity vector of particle } (i) \text{ in dimension } (j) \text{ at time } (t) \]
\[ x_{ij}^{t} = \text{Position vector of particle} \]
\[ P_{\text{best},i}^{t} = \text{Personal best position of particle } (i) \text{ found from Initialization through time } (t), \]
\[ G_{\text{best}} = \text{Global best position of particle } (i) \text{ found from Initialization through time } (t), \]
\[ c_{1} \text{ and } c_{2} = \text{Positive acceleration constants which are used for leveling the contribution of the cognitive and social components respectively,} \]
\[ r_{1}^{t} \text{ and } r_{2}^{t} = \text{Random numbers from uniform distribution } U(0,1) \text{ at time } (t) \]
The PSO control parameters used in the present study are detailed in Table 3.4.

**Table 3.4 PSO control parameters**

<table>
<thead>
<tr>
<th>Sl.No</th>
<th>PSO parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Number of Particles</td>
<td>20</td>
</tr>
<tr>
<td>02</td>
<td>Particle Dimensions</td>
<td>2 (Solution concentration, Soaking time)</td>
</tr>
<tr>
<td>03</td>
<td>Particle Ranges</td>
<td>Solution concentration (%) = [2 – 10]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soaking time (hrs) = [12 – 60]</td>
</tr>
<tr>
<td>04</td>
<td>Inertia factor</td>
<td>1.2</td>
</tr>
<tr>
<td>05</td>
<td>Number of cycle</td>
<td>5</td>
</tr>
<tr>
<td>06</td>
<td>Number of iteration</td>
<td>100</td>
</tr>
<tr>
<td>07</td>
<td>Learning factor</td>
<td>[c_1,c_2] = [1.5,1.5]</td>
</tr>
</tbody>
</table>

The steps followed during PSO optimization are listed below

**Step 1:** Create a ‘population’ of agents (particles) uniformly distributed over the search space

**Step 2:** Evaluate each particle’s position according to the objective function

**Step 3:** If a particle’s current position is better than its previous best position, update it

**Step 4:** Determine the best particle (according to the particles previous best positions)

**Step 5:** Update particles velocities

**Step 6:** Move particles to their new positions

**Step 7:** Go to step 2 until stopping criteria are satisfied

The treatment parameters were optimized concurrently in order to reach the optimum solution rapidly with less computational time. The solution space of the problem is restricted by the best solution of the previous iteration and the global optimum solution for the problem is reached within the limited search space resulted from best particles.
3.10 **SUMMARY**

- Two new varieties of natural fibers namely Dharbai and Christmas palm fibers were introduced as reinforcement materials in polyester matrix composites.

- The Dharbai and Christmas palm fibers extracted by means of water retting process were characterized for its physical, chemical and thermal properties.

- The Dharbai-polyester and Christmas palm - polyester composites were fabricated using compression molding technique and the procedure for conducting mechanical test (tensile, flexural and impact strength) on the fabricated composites was elaborated.

- The Dharbai and Christmas palm fibers were subjected to two types of alkali treatment (NaOH and KOH) at various treatment conditions. The treated fibers were reinforced in the polyester matrix and their mechanical properties were tested as a function of treatment parameters.

- Rapid I machine vision system, FTIR and XRD techniques were used to characterize the changes on the surface morphology, chemical structure and crystallinity of fibers upon alkali treatment.

- Regression modeling and Particle Swam Optimization (PSO) technique was employed for optimizing the mechanical behaviors of alkalized Dharbai - polyester and Christmas palm - polyester composites.