Scientia Iranica (2024) 31(8), 659–666

SCIENTIA IRANICA

Sharif University of Technology
**Scientia Iranica**
*Transactions B: Mechanical Engineering*
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# Python programming predictions of thermal behavioral aspects of orange peel and coconut-coir reinforced epoxy composites

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Received 3 April 2022; received in revised form 2 December 2022; accepted 19 June 2023

**KEYWORDS**
Thermal insulation;
Orange peel composites;
Coir composites;
Thermal properties;
Theoretical models.

**Abstract.** Using a hand lay-up approach, both orange peel and coconut coir fibres are used in particulate form with an epoxy matrix to create partly green biodegradable composites. The findings indicate great opportunities for employing these natural fibres. The thermal conductivity of orange peel and coconut-coir epoxy composites was measured experimentally for various volume fractions of particulate fibres. The experimental findings show that as fibre concentration increases, thermal conductivity decreases. Experimental data are compared to theoretical models to determine the change in thermal conductivity with fibre amount fraction. There was a clear correlation between the hypotheses and the actual results. Regression analysis using Python programming is also done for the prediction of the thermal properties of particulate orange peel and coconut-coir fibre composites. It is observed that coir fibre composites outperformed the orange peel, indicating that the coir fibre composite is a proper thermal insulator that can be used in many industries, like the automotive industry, buildings, and steam pipes, to reduce heat transfer and thereby save a lot of energy.



## 1. Introduction

Natural fibres are being used creatively in a variety of fields due to their advantages over synthetic fibres, such as being harmless to the environment, sustainable, having low thickness, weight, and cost, having a high specific stiffness, and being available in many agricultural nations [1,2]. Epoxy resins have excellent adhesive qualities and are easy to cure due to their non-volatile nature throughout the curing process. Their shrinkage is much reduced as compared to polyesters. Significant progress has been achieved when they are reinforced with other natural fibres in epoxy resin-based composites reinforced with natural fibres [3–5]. To reduce water retention and enhance the chemical bond between fibre and matrix, chemical treatments such as potassium permanganate, benzoyl

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**To cite this article:**
S. Pujari, P. Alekya, S. Sivarao, and M.D. Silas Kumar "Python programming predictions of thermal behavioral aspects of orange peel and coconut-coir reinforced epoxy composites", *Scientia Iranica* (2024), **31**(8), pp. 659-666
DOI: 10.24200/sci.2023.60206.6665

chloride, maleic anhydride, alkali, acrylic acid, silane, acetic anhydride, or a combination of both have been effectively used in fibers [6–8]. The flexibility of composites to be tailored for a specific purpose, particularly with particulate composites where the particles are dispersed evenly in the matrix, is a significant benefit. The incorporated particles in the matrix are referred to as fillers, and their function is to alter their properties. The composite's behaviour is directly related to particle size, matrix properties, volume filler proportion, and so on. Low temperature co fired ceramic is an example of a custom-made fiber composite that may be utilised as a substrate material to construct multilayer electronic components and sensor systems for automobiles, telecommunications, and healthcare systems [9]. Several thermal analysis investigations on polymers are aimed at increasing their thermal conductivity instead of helping to insulate the materials, something that has been widely used in thermo flasks, pipe insulation, food containers, building insulation, spacecraft, and the automotive sectors. The fundamental mechanical and thermal properties of numerous fiber reinforced plastics are improved through different manufacturing methods, and hence the analysis of thermal conductivity, stability, and degradation of any hybrid composite is quite essential. Research on eco-friendly and cost-effective thermosetting hybrid composites with unique mechanical and thermal properties are still in progress [10]. When compared to a conventional epoxy composite, the glass transition temperature (Tg) of a coconut coir-bagasse composite increases by up to 190°C, resulting in its usage in the building roofing and packaging industries. At 150°C, the initial deterioration was seen [11]. Chemical bonding, crystal structure, and low atomic density all contribute to polymer thermal conductivity [12] and an harmonicity in molecular vibrations [13], whereas phonon and lattice vibrations that cause thermal resistance are the reason for the heat transfer in non-metals [14].

Epoxy resin matrix is mostly preferred in the field of engineering due to its higher thermal and chemical resistance, compatibility with a wide range of materials, and cost-effectiveness compared to other thermosets. Thermal conductivity must be precisely measured to develop a constitutive model. There are two types of measuring techniques: Steady-state and transient. The hot-guarded plate technique of the steady-state method (codified in ISO 8302:1991 as well as ASTM C177-04) worked effectively in the context of measuring thermal conductivity for low-conductive, partly cured samples in solid form [15]. When glass fibers were included in the reinforced polyester composite banana fiber mix, it was discovered that the thermal property of the composite dramatically improved, which diminished with the rise in the amount of glass fiber [16]. The transient plane-source approach was used to investigate the effect of the volume percentage of pineapple leaf fibre on the thermal properties of composites, and the results show that the conductive behaviour of the fabricated composite decreases as the concentration of pine apple fibre in the filler increases [17]. The thermal characteristics of the composites were optimized, and it was revealed that employing groundnut shell particles improved their thermal properties [18]. It is common practise to utilise the Finite Element Methods (FEM) to simulate heat transport and thermal conductivity of composites, which is often used as a supplementary verification method for other strategies [19]. Alternative numerical techniques, such as a numerical approach for generating the geometry of synthetic diamond particles, have been presented in addition to FEM [20]. To calculate the needled nonwoven structure's effective thermal conductivity coefficient from its specific air permeability, a linear multiple regression analysis technique was used, which established a relation between thermal conductivity and air permeability [21]. The construction of complicated non-linear prediction models using regression analysis is a well-established technique for forecasting performance characteristics. The researchers built a mathematical model and used ANOVA to determine the model's adequacy [22]. Phase transition and plastic deformation mechanisms induced by self rotating grinding of GaN single crystals were evaluated. Results revealed that abrasive size had a notable effect on roughness and surface morphology in comparison with wheel rotational speed and feed speed. This work provides a clear understanding of the deformation and damage to crystals involved in the ultra precision machining process [23]. Anisotropy-dependent material removal and deformation mechanisms during nanoscratching of gallium nitride single crystals on the (0001) plane were evaluated. This study clarifies the anisotropy dependence of material removal and damage mechanisms, and it can be used as a guide to achieve high efficiency and low damage machining of GaN crystals [24]. Some researchers studied the effect of fibre orientation and number of layers on mechanical properties, which were evaluated experimentally. Results concluded that hybrid composites exhibit superior mechanical properties [25,26].

No study on the optimization of the thermal characteristics of orange peel and coconut-coir particle-reinforced polymer composite materials has been published in the literature. Natural fibres include orange peel and coconut coir particulates. Coconut coir is a natural fiber extracted from the husk of coconut and used in products such as floor mats, doormats, brushes, and mattresses. Coir is the fibrous material found between the hard, internal shell and the outer coat of a coconut. Other uses of brown coir (made from ripe coconut) are in upholstery padding, sacking, and horticulture. White coir, harvested from unripe coconuts, is used for making finer brushes, string, rope, and fishing nets. Orange is a citrus fruit native to Southeast Asia. It is the most commonly grown fruit in the world. An orange has a tough, shiny orange skin. Inside, the fruit is divided into "segments", which have thin tough skins that hold together many little sections with juice inside. There are usually ten segments in an orange, but sometimes there are more. Inside each segment of most types of orange there are seeds called "pips". The skin of some oranges is difficult to remove. With mandarin oranges, the skin, pith, and segments can all be pulled apart very easily. Orange skin is often called "orange peel". When compared to metal matrix composites, these fibres attract attention due to their superior properties such as light weight and low cost. Natural fiber-based composites are now being used in automobile industries, air craft components, and bulletproof panels. In addition to this, natural fibres are environmentally friendly because they are non-hazardous and biodegradable when compared to other synthetic fibre and metal matrix composites [27–30]. This work was done to compare the experimental work with regression analysis of an orange peel and coconut-coir particle reinforced composite materials.

## 2. Experimental

### 2.1. Materials

Orange peel and coconut-coir fibres were purchased from a local market in Visakhapatnam city and treated with NaOH solution before being neutralised with 5% acetic acid solution. Following that, the fibers were crushed into granular sized particles, which were then used as the untreated sample in this work. For matrix and curing, Araldite LY 556 was used, and to enhance its characteristics, an estimated amount of epoxy resin and hardener in the ratio of 10:1 by weight was considered and mixed with orange peel particulate. Natural fibres have no melting point. Epoxy has a melting point of 145°C-155°C. The fibres were then ground into particles, as shown in Figure 1(a) and (b). The collected powders were separated, and after sieving, a particle size of 100 microns was determined in accordance with BS 1377:1990.

(a) (b)

**Figure 1.** (a) Coconut coir and (b) Orange peel particulate forms.

### 2.2. Alkali treatment

The obtained orange-peel and coconut-coir fibres were each immersed in 5% sodium hydroxide for 4 hours at 30°C, following which they were rinsed several times in sterilised water to remove any sodium hydroxide residues from the surface of the composite. Afterward, it is neutralised with weak acetic acid and rinsed once more with sterilised water until the overall PH is stabilised at 7. Following this, the fibres were allowed to dry out in a room for 48 hours, after which they were put in an oven for 6 hours at 100°C to remove traces of dampness from the fabric. After the surface treatment of the fibers, they were only crushed into particles.

### 2.3. Composite fabrication

The orange peel and coconut-coir particles have been further refined by screening to ensure that the particle size remains consistent. The powdered products are weighted separately depending on the necessary amount to be blended with the matrix material and put into the mold. While curing at room temperature, hot air is allowed to escape by continuing to keep each opposite end open for a minimum of one day, and then post-curing it inside an oven for 8 hours at 60°. A similar procedure is adapted to obtain specimens depending on the desired thickness for orange peel and coconut-coir particulate-reinforced composites, respectively. Particulate orange peel and particulate coconut coir of size 100 microns were used in this work.

### 2.4. Thermal conductivity measurement

The ASTM E 1225-87 standard was used to prepare the circular discs, with a diameter of 70 mm and a thickness of 4 mm, taking the volume fractions of the particulate fiber composites as 20%, 40%, and 60%. Figure 2 depicts the experimental test rig used to perform the thermal conductivity test [31]. The thermal conductivity may be calculated using the relationships shown below:

$$q = (K(T1 - T2))/L, \quad (1)$$

$$R = (T1 - T2)/q, \quad (2)$$

$$K = L/R. \quad (3)$$

The experimental setup for evaluating the thermal properties of an orange and coconut coir fibre is shown in Figure 2. The hot flux experimental setup was used to determine the thermal conductivity of thermal insulators, which is based on unidirectional heat transfer at steady state in a system, composed of walls or sandwich-like structures (ASTM E 1225-87). There is a heat source that feeds the system.

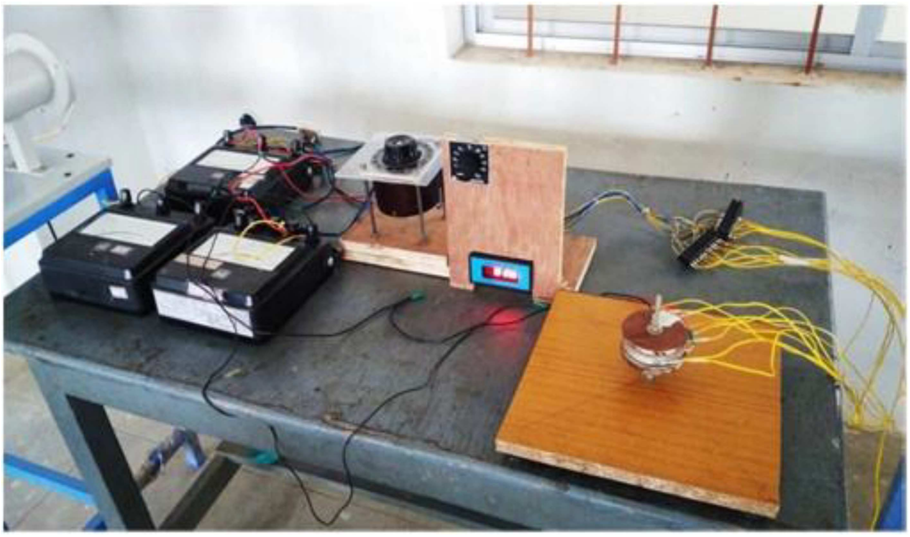

**Figure 2.** Thermal conductivity being measured in an experimental setting.

The experimental set-up consists of a heater and coil arrangement with ceramic beading. Heaters with a capacity of 300 W were used. The temperatures were measured with the help of thermocouples, and the measured temperatures were displayed on the temperature indicator. A dimmer stat was used, as well as a voltmeter, ammeter, and watt metre with capacities of 0–300 V, 0–5 A, and 0–200 W.

## 3. Results and discussions

The results of the study of different thermal properties are presented here. A code was generated by using the computer programming language Python to conduct a regression analysis, which was used to interpolate the values and reduce the number of experiments.

### *3.1. Thermal conductivity*

As the fibre concentration of the composite increases, so does its thermal conductivity. It occurs as a result of the presence of air in the hollow section of the reinforced fibre, which increases in proportion to the amount of fibre present. It is because of the thermal conductivity of air is 0.024 W/mK. It is much less than the thermal conductivities of particulate orange peel and coconut coir. Due to the lower thermal conductivity of air, the insulation property increases. The trend is depicted in the plots presented in Figures 3 and 4.

To determine their attributes and expressions, the observed thermal conductivities are compared with standard models as shown below [32]:

Series model:

$$1/K_c = V_f/K_f + (1 - V_f)/K_m, \quad (4)$$

Hasin model:

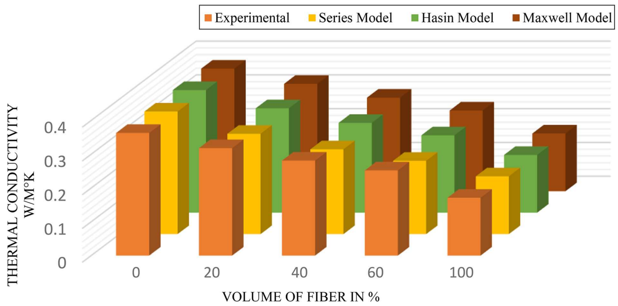


**Figure 3.** Analysis of the thermal conductivities of orange peel composites by various methods.

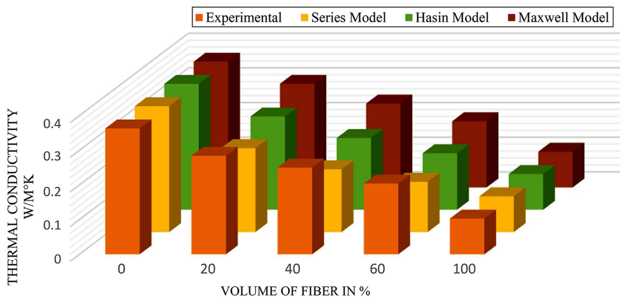


**Figure 4.** Analysis of the thermal conductivities of coconut-coir composites by various methods.

$$K_c = (K_f(K_f.V_f + K_m(1 + V_m)))/(K_f(1 + V_m) + K_m.V_f, \quad (5)$$

Maxwell model:

$$K_c = (K_m(Kf + 2K_m - 2V_f(K_m - K_f)). \quad (6)$$

The volume fraction of fibre, which is referred to as $V_f$, is indicated here. A composite, fiber, and matrix have thermal conductivities of $K_c$, $K_f$, and $K_m$ correspondingly. See Figures 3 and 4 for practical and theoretical findings on orange peel and coconut-coir composites.

The results of both experimental and theoretical models are much closer at lower volume fractions, but as we get higher, the theoretical models tend to dominate. This is usually because the assumptions used in such models are not linearly viable in the majority of cases. Within the theoretical model, an assumption is made that the alignment of the fibres is ideal. However, in reality, they are misaligned.

Coconut-coir composites have the least thermal conductivity than orange peel composites, which is shown in Figure 5. These results show that coconut coir composites have better insulation properties and can therefore be used in manufacturing components that require reduction of heat transmission, especially in air-conditioned buildings, which is a concern for reducing energy consumption, and hence may be used as building components in the construction of such structures.

### *3.2. Regression analysis*

Researchers in multiple domains usually use regression as a statistical approach to describe the nature of the relationship between variables. The variables' relationships with one another can be linear or non-linear, positive or negative. The factors in regression are divided into independent and dependent variables. The independent variable can be used to predict the dependent variable, which is a response variable. The

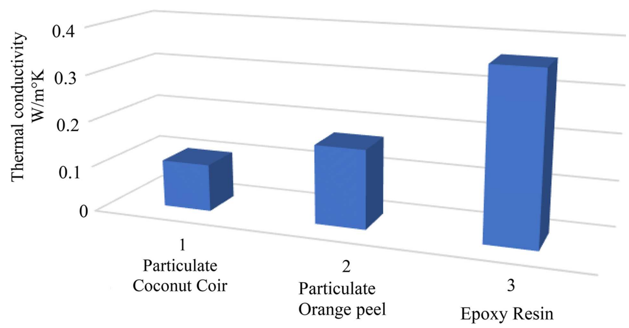


**Figure 5.** Values of thermal conductivities for various composites.

regression analysis is also known as the dependent variables as a result [33–35].

In the study, it is essential to report the effect of thermal conductivity values on the change in the volume fraction for different materials like orange peel and coconut-coir particulate composites. By employing regression analysis, it is possible to extrapolate the findings acquired from the values collected by the tests (recorded in Table 1). A computer programme was generated by using Python for regression analysis. The polynomial equations to indicate the thermal conductivity values of orange peel and coconut-coir fibre composites are given below:

$$y = -2.3325X10^{-3}x - 7.708328X10^{-7}x^2 + 2.93749999X10^{-7}x^3 - 2.44791666X10^{-9}x^4 + 0.363, \cdots \quad (7)$$

$$y = -6.662500X10^{-3}x + 1.859375X10^{-4}x^2 - 2.781250X10^{-6}x^3 + 1.328125X10^{-8}x^4 + 0.363, \cdots \quad (8)$$

where '$y$' denotes thermal conductivity and '$x$' denotes particle fibre volume percentage. The thermal conductivity values for various composites as determined by regression analysis are shown in Figure 6.

### *3.3. Thermal diffusivity*

The thermal diffusivity values for various composites are shown in Figure 7. It may be inferred that composites improve diffusivity as a result of fibrous reinforcement. When the volume percentage of fibres is increased, the thermal diffusivity increases proportionately. The orange-peel-based composites diffuse heat more significantly compared with coconut-coir composites. This is often a consequence of the chemical composition of orange peel, which happens to contain more hemicelluloses and lignin.

**Table 1.** Comparison of thermal conductivities of orange peel and coconut-coir composites Interpolated from regression analysis.

| **Volume of fiber%** | | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Thermal conductivity of composites (W/m°K) | Orange peel | 0.363 | 0.351 | 0.339 | 0.328 | 0.318 | 0.307 | 0.298 | 0.289 | 0.281 | 0.273 |
| | Coconut-coir | 0.363 | 0.333 | 0.312 | 0.296 | 0.284 | 0.274 | 0.266 | 0.258 | 0.250 | 0.240 |

| **Volume of fiber%** | | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Thermal conductivity of composites (W/m°K) | Orange peel | 0.265 | 0.258 | 0.252 | 0.245 | 0.237 | 0.230 | 0.221 | 0.211 | 0.200 | 0.186 | 0.171 |
| | Coconut-coir | 0.230 | 0.217 | 0.204 | 0.188 | 0.172 | 0.156 | 0.140 | 0.12 5 | 0.113 | 0.105 | 0.103 |

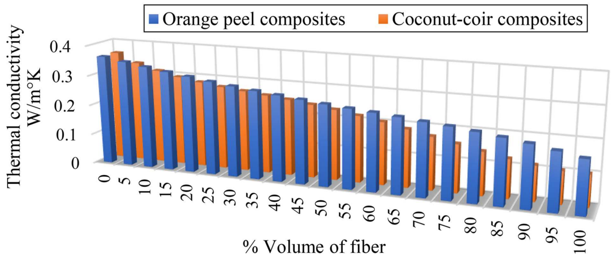


**Figure 6.** Comparative analysis of thermal conductivity values of particulate Orange peel and Coconut-coir composites.

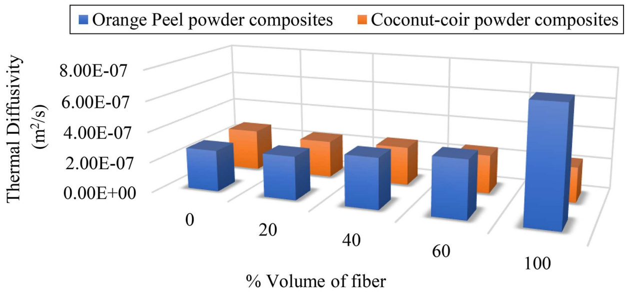


**Figure 7.** Comparative analysis of thermal diffusivity values of particulate orange peel and coconut-coir composites.

## 4. Conclusions

It was described how to use regression analysis to interpolate thermal conductivity values based on the volume percentage of particle fibres. The approach allows application engineers to determine the thermal behaviour of natural fibre composites without having to conduct extensive tests that cost a lot of money and time. The thermal conductivity of orange peel composites ranged from 0.252 W/m°k for temperatures between $-20$°C and 300°C, whereas that of coconut-coir composites ranged from 0.204 W/m°k. Because fibres are non-conductive, the thermal conductivity of composites decreased as the percentage of fibre volume increased. Orange peel and coconut-coir composites had thermal diffusivity values of 3.74 X$10^{-7}$m$^2$/s and 2.52 X$10^{-7}$m$^2$/s, respectively. When compared to orange peel composites, coconut-coir composites had the lowest thermal conductivity. As a result, natural fiber composites can be used as thermal insulators because of their particle nature.

These composites can be utilised as insulation materials in aircraft applications due to their low weight and good thermal characteristics. The results are similar at low fiber percentages. However, as fibre content increases, the error in the Series and Hasin models increases, while the error in the Maxwell model decreases.

## Nomenclature

| | |
|---|---|
| NaOH | Sodium Hydroxide |
| ASTM | American Society for Testing and Materials |
| FEM | Finite Element Method |
| ANOVA | Analysis of Variance |
| ANN | Artificial Neural Networks |
| DOE | Design of Experiments |
| Q | Heat Transfer Rate, W |

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## Biographies

**Satish Pujari** has served as Design Engineer at various industries and as Assistant and Associate Professor at premier institutes in India since 2007. He received a PhD degree in Mechanical Engineering from Andhra University, India. He is presently working as a Professor and HOD in the Department of Mechanical Engineering, Lendi Institute of Engineering and Technology, Vizianagaram. He honored with best teacher awards in three consecutive academic years from her qualitative services for teaching. He is a life member in several professional societies. His research interests include Nano materials, Composite materials, Smart materials, Tribology and Bio-medical Engineering and Materials processing. He filed 3 Indian Patents among them, all published in the Indian Patent Journal, Govt. of India and also he is editor of One Textbook published by Springer. He published few Book chapters, and he is a reviewer of many international journals. His papers appeared in various International Academic Journals and conferences such as Springer, SAGE, Elsevier and Inderscience etc. He has AICTE funded project of worth 12.5 lakhs.

**Pilla Alekya** was born in Visakhapatnam, India. She received her BE degree in Mechanical Engineering from SVP Engineering College, Visakhapatnam under Andhra University, India, in 2013. Now she is pursuing her M.Tech. degree in Machine Design from Lendi Institute of Engineering and Technology.

**Sivarao Subramonian** has served as a mechanical engineering lecturer with three premier Polytechnics in Malaysia since 1989. He then, joined Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka in year 2003. Professor Ir. Ts. Dr. Sivarao has also rolled as the Inaugural Director for Technology Transfer Office (TTO), and as the Deputy Director for Research and Innovation Management Centre (RIMC). Being a Certified Professional Engineer, he is very passionate about translating research and innovation outputs from universities into the benefits ofindustries and communities. Thus, he actively conducts talent development workshops to Universities and Research Institutes employing specially tailored modules to generate high-impact research outcomes. He is also a Certified Technology Transfer Professional accredited by ATTP, UK. Besides, he is also a Competent Train-The-Trainer, certified by Ministry of Human Resources Malaysia. His research interests are Innovative Mechanical Engineering and Design, Advanced Manufacturing, Additive Manufacturing, Advanced Machining, Composite Materials, Materials Processing, and Process Modelling and Optimization employing Statistical, Artificial Intelligence, and Expert Systems. He now has contributed 200+ peer reviewed indexed scientific publications, 60+ research grants, 20+ patents, 50+ innovation awards, 30+ consultation projects, 50+ invited speaker and workshop trainer, 20+ PhD and MSc postgraduates, and many other attributes related to research and teaching.

**Daniel Silas Kumar Mandrumaka**, completed his masters in CAD/CAM from the department of Mechanical Engineering, Andhra University. He has more than 10 years of teaching experience and 4years in research have published various other paper. His research is based on High Entropy alloys. His other interest also includes in 3D printing, Robotics and Drone technology. He is currently working at Lendi institute of Engineering and technology, Vizianagaram as an Assistant Professor.