Prediction of Surface Roughness in Turning Alkaline Treated Banana Fiber Reinforced Epoxy Composite under Compressed Cooling Air Condition

By

Md. Rezaul Karim

A Thesis
Submitted to the
Department of Industrial & Production Engineering
in Partial Fulfilment of the
Requirements for the Degree
of
MASTER IN INDUSTRIAL & PRODUCTION ENGINEERING

DEPARTMENT OF INDUSTRIAL & PRODUCTION ENGINEERING
BANGLADESH UNIVERSITY OF ENGINEERING & TECHNOLOGY
DHAKA, BANGLADESH

January 2020

The thesis titled **Prediction of Surface Roughness in Turning Alkaline Treated Banana Fiber Reinforced Epoxy Composite under Compressed Cooling Air Condition** submitted by **Md. Rezaul Karim**, Student No. 1014082028 P, Session- October 2014, has been accepted as satisfactory in partial fulfillment of the requirement for the degree of M.Sc. in Industrial and Production Engineering on 4th January, 2020.

BOARD OF EXAMINERS

1. Dr. Nikhil Ranjan Dhar — Chairman (Supervisor)
Professor
Department of Industrial & Production Engineering
BUET, Dhaka

2. Dr. Nikhil Ranjan Dhar — Member (Ex-officio)
Head
Department of Industrial & Production Engineering
BUET, Dhaka

3. Dr. Shuva Ghosh — Member
Associate Professor
Department of Industrial & Production Engineering
BUET, Dhaka.

4. Md. Abdus Salam — Member (External)
Professor & Head
Department of Aeronautical Engineering
MIST, Dhaka

Declaration

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

Md. Rezaul Karim

This work is dedicated
to my loving

Father

&

Mother

Table of Contents

List of Figures

List of Tables

List of Symbols

V_c	: Cutting Speed
S_0	: Feed rate
t	: Depth of Cut
R_a	: Average Surface roughness
Pz	: Main cutting Force

Acknowledgement

I express my deepest thanks to Almighty Allah, the most beneficent and the most merciful for giving me potentiality and patience complete this thesis effectively.

I express my sincere gratitude and profound gratefulness to my respected supervisor Dr. N. R. Dhar, Professor, Department of Industrial & Production Engineering, BUET, Dhaka, for his continuous support, timely advices, thoughtful guidance, encouragement, motivation and valuable suggestions throughout the progress of this work.

I would like to thank the board of examiners Dr. Shuva Ghosh, Associate Professor, Department of Industrial & Production Engineering, BUET and Md. Abdus Salam, Professor, Department of Aeronautical Engineering, MIST for their suggestions and guidance.

I acknowledge the assistance provided by the Director, DAERS, BUET who provided central machine shop facilities. Special thanks to all the staff memebers of central machine shop and Machine Tools Lab, especially M. A. Razzak, and S. C. Das for their helps in conducting the experimental work. I would like to thank Bangladesh Council of Scientific and Industrial Research (BCSIR), for the permission to use their lab facilities. Furthermore, I would like to express my gratitude to Mr. Martin Ronald Pramanik, Manager (Production) of MAWTS Institute of Technology for helping me to develop the composite material.

Finally, I would like to convey my deepest gratitude to my parents for their inspiration, support and unconditional love throughout my life.

Abstract

In modern days, material engineers are constantly striving to develop new composite materials due to its lightweight, high specific strength and high specific modulus are being considered as some remarkable properties that can be facilitated with their applications in various automobile and engineering sectors. Alkaline treated banana fiber is gaining popularity due to its comparison to conventional glass fiber. In this study machinability of alkaline treated banana fiber, reinforced polymer has been compared with traditional glass fiber. Among various machining environments, which have been evolved to cut fiber-reinforced polymer, compressed air cooling environment has been found very effective in machining FRPs when surface roughness and cutting force are taken into consideration.

In this research work, turning operation of alkaline treated banana fiber reinforced epoxy was performed under both dry and compressed air cooling condition. Experimental Investigation was carried upon to compare the performances of two machining environments. Cutting speed, feed rate and depth of cut have been considered as input cutting parameters whereas resultant outputs are surface roughness and cutting force. A predictive model of surface roughness was developed using artificial neural network (ANN) which has been validated against the experimentally found results. Furthermore, Response Surface Methodology (RSM) was used to develop a quadratic equation to compare it with the experimental value. Using desirability function analysis, optimum cutting condition has been found while machining BFRP composite under compressed air cooling condition, the optimum cutting parameters which yielded the desired output responses (surface roughness and cutting force) ; R_a =2.511 µm, P_z = 15.457 N are follows: 0.403 mm of t, 55 m/min of V_c and 0.116 mm/rev. For ANN developed model, regression value is found to be 0.99518 for banana fiber reinforced epoxy composite under compressed air cooling condition which is very close to 1, thus justifying the efficacy of the developed model.

Chapter-1

Introduction

A Composite material is a material made from two or more constituent materials with significantly different physical properties, when combined, produce a material with characteristics different from individual one. Many natural and artificial materials are of this nature, such as: reinforced rubber, filled polymers, mortar and concrete, alloys, porous and cracked media, aligned and chopped fiber composites, polycrystalline aggregates (metals), etc. This type of composite is used extensively throughout our daily lives. Common everyday uses of fiber reinforced plastic composites include: Aircraft, Boats and marine, Sporting equipment (Golf shafts, tennis rackets, surfboards, hokey sticks, etc.) Automotive components, Wind turbine blades, Body armor and Water pipes and ladder rails. [**Hashin Z. 2009**]

1.1 Natural Fiber Reinforced Polymer Composite

The increase in environmental consciousness and community interest, the new environmental regulations and unsustainable consumption of petroleum, led to thinking of the use of environmentally friendly materials. Natural fiber is considered one of the environmentally friendly materials which have good properties compared to synthetic fiber [**Maypat et. al 2013**] Natural fiber polymer composites (NFPC) are a composite material consisting of a polymer matrix embedded with high-strength natural fibers, like jute, oil palm, sisal, kenaf, and flax . Usually, polymers can be categorized into two categories, thermoplastics and thermosets. The structure of thermoplastic matrix materials consists of one or two-dimensional molecules, so these polymers have a tendency to make softer at a raised heat range and roll back their properties throughout cooling. On the other hand, thermosets polymer can be defined as highly cross-linked polymers which cured using only heat, or using heat and pressure. This structure gives to thermoset polymer good properties such as high flexibility for tailoring desired ultimate properties, great strength, and modulus. Thermoplastics widely used for biofibers are polyethylene, polypropylene (PP) , and poly vinyl chloride (PVC); here as phenolic, polyester, and epoxy resins are mostly utilized thermosetting matrices [**Wang et. al 2011**]. Different factors can affect the characteristics and performance of NFPCs. The hydrophilic nature of the natural fiber and the fiber loading also have impacts on the composite properties. Usually, high fiber loading is needed to attain good properties of NFPCs. Generally, notice that the rise in fiber content causes improving in the tensile properties of the composites. Another vital factor that considerably impacts the properties and surface characteristics of the composites is the process parameters utilized. For that reason, appropriate process techniques and parameters should be rigorously chosen in order to get the best characteristics of producing composite. The chemical composition of natural fibers also has a big effect on the characteristics of the composite represented by the percentage of cellulose, hemicellulose, lignin, and waxes [**Faruk et. al 2010**].

The properties of natural fiber composite are different to each other according to previous studies, because of different kinds of fibers, sources, and moisture conditions. The performance of NFPCs relies on some factors, like mechanical composition, microfibrillar angle, structure, defects, cell dimensions, physical properties, chemical properties, and also the interaction of a fiber with the matrix [**Dai and Fan 2014**]. Since every product in market has drawbacks, similarly, natural fiber reinforced polymer composites also have drawbacks. The couplings between natural fiber and polymer matrix are problem taken into consideration, as a result of the difference in chemical structure between these two phases. This leads to ineffective stress transfer during the interface of the NFPCs. Thus, the chemical treatments for the natural fiber are necessary to achieve good interface properties. The reagent functional groups in the chemical treatments have ability to react on the fiber structures and alter the fiber composition. Natural fibers include a functional group named as hydroxyl group which makes the fibers hydrophilic. During manufacturing of NFPCs, weaker interfacial bonding occurs between hydrophilic natural fiber and hydrophobic polymer matrices due to hydroxyl group in natural fibers. This could produce NFPCs with weak mechanical and physical properties [**Shinoj et. al 2011**].

There are considerable enhancement and suggestions for the natural fibers that can be implemented in order to enhance their mechanical properties resulting in high strength and structure. Once the base structures are made strong, the polymers can be easily strengthened and improved [**Srinivasan et. al 2014**]. There are number of aspects that affect composite performance level, of which to name a few are the following:

(a) Orientation of fiber
(b) Strength of fibers
(c) Physical properties of fibers
(d) Interfacial adhesion property of fibers and many more.

NFPCs are such composites whose mechanical efficiency is dependent upon the interface provided by fiber-matrix along with the stress transfer function in which stress is transferred to fiber from matrix. This has been reported by many investigators in several researches. Characteristic components of natural fibers such as orientation, moisture absorption, impurities, physical properties, and volume fraction are such features that play a constitutive role in the determination of NFPCs mechanical properties. Mechanical properties of PLA, epoxy, PP, and polyester matrices can be affected by many types of natural fibers [**Ramesh et. al 2014**]. NFPCs show even better mechanical properties than a pure matrix in cases where jute fibers are added in PLA (polylactic-acid); in this case, percentage of PLA's tensile strength was improved; however, introduction or incorporation of flax fibers showed a negative impact on this addition. The addition of flax fibers resulted in 16% reduced tensile strength of the composites. Conversely, composites of PP were improved with the incorporation of hemp, kenaf, and cotton. By far, maximum improvement is only seen in such composites where jute or polyester has been incorporated where a total of 121% improvement is evident compared to pure polyester [**Shalwan and yousif 2013**].

In the presence of flame, burning of composites takes place in five different steps as shown below:(a) Heating (b) Decomposition (c) Ignition (d) Combustion (e) Propagation. If flame retardancy has been achieved in the aforementioned steps, no matter whether ignition step has been conducted or not, the procedure will be terminated before an actual ignition is set up. There are two forms of products that are obtained upon burning of composites; these two include high cellulose content and high lignin content. High cellulose provides chances of higher flammability whereas higher values of lignin show there is a greater chance of char formation. Thermal resistance is provided by flax fibers;

however, silica or ash is another important feature that is helpful in extinguishing fire [**Sain et. al 2004**].

In order to enhance fire resistance of various NFPCs, different procedures are undertaken. Fire barriers are kind of barriers that can be applied to phenolics, ceramics, glass mats, silicone, ablatives, and chemical additives too. Coatings and additives used in the system of intumescent are found to be very promising fire barrier treatments in which these barriers are expanded upon heating resulting in a cellular surface that is charred evenly. However, with the help of this charred surface, internal or underlying components and protected against flux and heat [**Fatima and Mohanty 2011**].

One of the well-known or profound flame-retardants for reinforced polymers (natural fibers) is used with the combination of char developing cellulose material. The only method of reducing combustion in this scenario is through increasing stability and char formation in the polymer. This will result in reduced flammability, decrease visible smoke, and restrict the volume of products produced due to combustions. Fire retardant coating is another method that helps in enhancement of fire resistance property of composites. This coating is done at the end or finishing stage or impregnation. Due to changes in the fibers and lingo-cellulosic particles, fire resistance is altered during the process of manufacturing [**Surdana et. al 2011**].

High strength composites are resultant products of natural fiber reinforcement in polymers which also provide extra or improved biodegradability, low cost, light weight, and enhanced properties related to mechanical structure. At temperatures, as high as 240°C, natural fibers start degrading whereas constituents of fiber, such as hemicelluloses, cellulose, lignin, and others, start degrading at different levels of temperature; for example, at 200°C lignin starts to decompose whereas at temperatures higher than this other constituent will also degrade [**Kabir et. al 2012**].

Since thermal stability of the fibers is dependent on the structural constituents of fibers, it can be improved if the concentration levels or the structural constituents are completely removed, such as lignin and hemicelluloses. This can be achieved with the help of chemical treatments. Development of fibers and materials that provide services are two important aspects which should be considered while degradation natural fibers. Natural fibers have a short lifetime with minimum environmental damage upon degradation whereas synthetic ones affect environment due to pollution caused by degradation. Lignin, hemicelluloses, and cellulose concentrations or composition affect thermal degradation features of lingo-cellulosic materials. More than fifty percent weight of jute or Biopol composite is lost after exactly 1500 days of burial [**Mohanty et. al 2000**].

Natural fibers work well as reinforcement in polymers. However, the main weakness of the application of natural fibers is their susceptibility to moisture [**Thomas and sreekala 2003**] Mechanical properties of polymeric composites have a strong dependence on the interface adhesion between the fiber and the polymer matrix. The natural fibers are rich of cellulose, hemicelluloses, lignin, and pectin, all of which are hydroxyl groups; that is, they are usually hydrophilic sources and strong polar whilst polymers show considerable hydrophobicity. Thus, there are major challenges of suitability between the matrix and fiber that weakens interface region between matrices and natural fibers [**Shalwan and yousuf 2013**]. At the composite materials' outer layers, water absorption happens and decreases gradually into the bulk of the matrix. A generally high-water intake by composite materials results in an increased weight of wet profiles, a conceivable decline in their strength, and increment in their deflection, swelling, and causing pressure on nearby structures. These can cause warping, buckling, bigger possibility of their microbial inhabitation, freeze, and unfreeze caused destruction of mechanical characteristics of composite materials [**Ghani and Ahmad 2011**]

The whole thesis can be divided into four basic parts. In the first part, fabrication of the natural fiber reinforced composite material for this research work will be presented. In the second part, strength of the treated and untreated banana fiber reinforced composite will be tested. In the third part, experimental investigation of the machining of composite material will be conducted under compressed air cooling machining environments. In the final part, for predicting surface roughness an artificial neural network model will be developed and machining parameter will be optimized using response surface methodology.

Chapter-2

Literature Review

2.1 Introduction

The utilization of natural fiber as a reinforced material can be traced back more than 10,000 years ago [**Mwaikambo 2006**]. However, it's application in manufacturing industries gradually was replaced by synthetic fiber like glass, carbon and aramid fiber. These composite performance characters such as strength to weight ratios and modulus to weight ratios are markedly superior to those of metallic materials, and natural fiber reinforced composite. For these reasons, synthetic fiber reinforced polymers have emerged as a major class of structural materials and are widely used as substitution for metals in many weights critical components in aircraft, aerospace, automotive, marine and other industries [**Mallick 2008**]. On the other hand, these advantages cause environmental problems in disposal synthetic fiber reinforced composite by incineration [**Nishino et. al. 2003**]. Over the past decades, the awareness of environmental impact, depletion of oils and gases resources and increasing concern of greenhouse effect has become one of a critical factor in developing and manufacturing a new product. Beside the product cost, functionality and reliability, the element of "sustainability", "eco-friendly" and "green material" had become a major requirement in new products designing [**Kaebernick and Sun 2003**].

2.2 Properties of Banana Fiber Reinforced Composites

In today's modern world the need for more efficient material is very significant for the development of new products. For these composites play a major role as it has strong load carrying material embedded in weaker material. Reinforcement provides strength and rigidity to help and support the structural load. Polymer matrix composites are widely used but the mechanical properties of polymers are inadequate for many structural purposes

[**Cheung et. al. 2009**]. In particular their strength and stiffness are low compared to ceramics and metals. These difficulties are overcome by reinforcing other materials with polymers. Applying natural fibers as reinforcing material in polymer composites is underway in various researches. Banana fiber can be easily obtained from the pseudo stem after the fruits and leaves are utilized. Researchers [**Chandramohan 2011, Mohan Rao et al. 2010 and Thomas 2003**] have been involved number of investigations on several types of natural fibers such as bamboo, kenaf, hemp, flax, and jute to study the effect of these fibers on the mechanical properties of composite materials.

Venkateshwaran et al. [**2011**] studied the mechanical properties of tensile, flexural, impact and water absorption tests were carried out using banana/epoxy composite material. Thiruchitrambalam et al. [**2009**] studied the effect of alkali and SLS (Sodium Lauryl Sulphate) treatment on Banana/Kenaf Hybrid composites and woven hybrid composites. Thermosetting resins are costly and the thermosetting resins commonly used in engineering applications are epoxy which has better mechanical properties. The thermoplastics offer recycling possibilities whereas the thermosets achieve improved mechanical properties. Polyester resins are low cost materials. Vinyl ester resins make a compromise between the above two limits. They have low properties comparing with epoxy, but are available at low cost.

The mechanical behavior of a natural fiber based polymer composite depends on numerous factors, for example, fiber length and quality, matrix, fiber-matrix adhesion bond quality and so forth. The strong interface bond between fiber and matrix is paramount to show signs of improvement in mechanical properties of composites.

Merlini et al. [**2011**] studied the effect surface treatment on the chemical properties of banana fiber and reported that treated banana fiber gives higher shear interfacial stress and tensile strength when compared with the untreated fiber. Dhieb et al. [**2013**] considered about the surface and sub-surface degradation of unidirectional carbon fiber and gave many conclusions such as under sliding in demineralized water, the simplest degradation was detected on sliding in anti-parallel direction. Shankar et al. [**2013**] studied and reported that the ultimate tensile strength value maximum at 15% and then decreases with increasing in fiber starting from 15% to 20%. They also reported that the flexural strength value decreasing from 5% to 10% (87.31 MPa) and after that the value increased from fiber.

Sumaila et al. [**2013**] investigated the influence of fiber length on the mechanical and physical properties of nonwoven short banana, random oriented fiber and epoxy composite and they described that the tensile properties and percentage elongation of the composite attained a maximum in composite fabricated from 15 mm fiber length. They have also reported that the impact energy whereas the compressive strength increases, decreased with increasing fiber length, also the mean flexural properties of the composite increased with increasing in fiber length up to 25mm. The banana fibers characteristic depending on the variation of diameter, mechanical characteristic and the effects of the stresses performing on the fracture morphology. The stress-strain curves for changed strain rates were found and fractured surfaces were inspected by SEM.

Pothan et al. [**1997**] have investigated on the influence of fiber content and length on short banana fiber reinforced polyester composite material. Laban et al. [**2001**] studied on the physical and mechanical behavior of banana fiber reinforced polymer composite and noticed that mashed banana fiber material has better flexural strength. The tensile strength is detected maximum at 30 mm fiber length whereas the impact strength is noticed maximum at 40 mm length of fiber. Consolidation of 40% untreated banana fibers gives 20% rise in the tensile strength and 34% rise in impact strength. Prasanna and Subbaiah **[2013]** reported that composites material having 20% treated fiber loading possess maximum values for above-mentioned properties than untreated composites, 10% and also 30% treated fibers composites. The interfacial area having main role in influencing the strength of polymer material since fiber procedures a separate interface with the matrix. The effects of this study uncovered that short zig-zag fiber composites with great rigidity and element mechanical properties might be effectively ready utilizing banana fiber as reinforcement in a polyurethane matrix inferred from castor oil. The treated banana fiber demonstrated higher shear stress and tensile strength when contrasted with the untreated fiber, showing a solid association between the treated strands and the polyurethane matrix [**Merlini et al. 2011**].

The hybridization of these reinforcement in the composite shows more terrific flexural quality when contrasted with singular kind of characteristic strands strengthened composites. All the composites show expand in flexural quality in longitudinal loading. Comparable patterns have been watched for flexural modulus, entomb laminar shear quality and break burden values [**Madhukiran et al. 2013**]. There are many researches who have evaluated the mechanical, chemical and physical behavior and banana fiber reinforced with epoxy composite. Many studied and compared the effect of treated and untreated banana fiber reinforced with thermoplastic and thermosetting polymer [**Thomas et al. 2008**].

Joseph et al. [**2002**] studied and compared the mechanical behavior of phenol formaldehyde composites which was reinforced with glass fiber and banana fiber. They also studied the carbon fiber reinforced polymer composites and reported that the brittle materials demonstrate a lot of delamination. This implies that in composites with an exceptionally intense grid and great fiber-network bond, various splitting, which ingests a higher measure of vitality, is anticipated, with the goal that at last confined disappointment happens at easier levels than anticipated. There is wide range of research in these fields; many researchers have investigated the natural fiber composite reinforced with various type of polymer [**Reddy 2013 and Haidi 2012**]. The banana and glass fiber bio-composites may be fabricated for outdoors and indoors applications wherever high strength is not necessary, additionally it can be considered as the replacement to wood materials and protect the forest resources.

Maleque et al. [**2007**] observed the mechanical properties of banana fiber based epoxy composite and it was observed that the tensile strength is increased by 90% of the pseudo-stem banana fiber reinforced epoxy composite associated to virgin epoxy. In his results, the impact strength of pseudo-stem banana fiber improved by approximately 40% compare to the impact strength of neat epoxy. The impact strength value is higher which indicate to higher toughness value of the material. They further reported that when banana woven fiber was used with epoxy material then the flexural strength increased. There are many reports available on the mechanical and physical properties of natural fiber reinforced polymer composites, but, the effect of fiber length on mechanical behavior of banana fiber reinforced polymer composites is scarcely being reported.

2.3 Machining of Composites

Machining of composite materials differs significantly in many aspects from machining of conventional metals and their alloys [**Komaduri 1997 and Hung 2002**]. In the machining of composites, the material behavior is not only non-homogeneous and anisotropic, but it also depends on diverse reinforcement and matrix properties, and the volume fraction of matrix and reinforcement. The tool encounters alternatively matrix and reinforcement materials, whose response to machining can be entirely different. Machining of these composites depends on the properties of fibers and matrix and their effects on the machining process [**Komaduri 1997**]**.** In polymer matrix-based composite systems the most common reinforcing material is glass and carbon fibers, while the matrix can be a thermoplastic or a thermosetting resin polymer. Machining of these fiber-reinforced polymer matrix composites has been extensively studied experimentally. These materials are shown to cause excessive tool wear, which in turn induces such damage phenomena as fiber pullout, delamination and de-bonding. This severe tool wear in the case of both carbon and glass fiber reinforced composites is due to the abrasive nature of the fibers.

The study done by Koplevetal. [**1983**] is considered as one of the first real attempts to understand the machining behavior of fiber- reinforced composites. They conducted orthogonal machining tests on carbon fiber-reinforced polymeric (CFRP) composites and observed the chip formation, surface quality and cutting forces for two fiber orientations i.e., perpendicular and parallel fiber orientations relative to the cutting direction. Two important results were observed. One is the chip formation mechanism was a series of fractures observed in the fibers and a rougher surface was observed from fiber orientation samples as compared to normal fiber orientation. In another earlier work Koenig et al. [**1985**] studied machining of fiber reinforced polymer (FRP) based composite materials, by a number of processes such as drilling, routing, turning, milling and water jet cutting. In this classical work, details of various damage phenomena were observed during machining of fiber reinforced composites: namely, fiber de-bonding, spalling, cracking of the matrix, fiber failure and fiber pull out. In another study Takeyama and Iijima [**1988**] described the chip formation process in the machining of a glass-fiber-reinforced polymeric (GFRP) composite. They observed that chip formation is highly dependent on the fiber orientation with respect to the cutting direction and observed metal-like chip formations while machining the composite with a thermoplastic matrix as opposed to a thermosetting resin polymer matrix.

Kim et al. [**1992**] conducted orthogonal tool wear tests on CFRP specimens. Fiber orientation angle and cutting speed were the major contributors to the flank wear, which was the major wear phenomenon observed. The tool wear was caused due to the very abrasive nature of the carbon fiber. It was also shown that fiber orientation and feed affected the surface roughness more than cutting speed.

The next major study was conducted by Wernand Ramulu [**1997**]**,** on the influence of fiber orientation on the cutting forces and fiber pullout in glass fiber reinforced composites(GFRP). They concluded that the tool with a positive rake angle resulted in the least amount of damage in the machined composite and lower cutting force. Tests measured in a counter clock wise direction from the cutting direction. Other studies also addressed the effect of cutting parameters, tool geometry and fiber orientation on the sub-surface damage observed in machined samples [**Nayak and Bhatnagar 2005**]**.** The results once again corroborated earlier findings on the effect of fiber orientations on the damage, lower cutting forces for higher fiber orientations, consequently resulting in less damage.

Nayak and Bhatnagar [**2005**] showed that the cutting force and the sub-surface damage increased with increasing fiber orientation while the rake angle had no or minimal effect on the cutting forces and the observed damage. Further studies have been conducted to investigate the delamination during drilling [**Campos rubio et al. 2007**]**.** Hocheng and Tsao [**2006**] examined the critical thrust force at the onset of delamination and showed the effects of drill bit geometry on the thrust force and hence the delamination. Campos Rubio et al. [**2007**] and Karniketal. [**2008**] investigated the effects of drilling parameters on delamination of fiber reinforced plastics and showed that higher speed, among others, could reduce delamination due to higher cutting temperature. The effects of various parameters on delamination were also summarized by Abrao et al. [**2007**]**.**

Ceramic fiber-reinforced metal matrix composites have seldom been machined with conventional machining methods. The fibers can be either short or long and continuous as governed by their application. The reinforcements enhance the properties of the metal matrix by increasing fracture toughness, resistance to high temperatures, strength and damage tolerance. The composite properties are highly dependent on the type of reinforcement as the mode of failure will differ. Continuous fiber reinforcements are stiffer than particulate or whisker reinforcements in the fiber direction. Similar to monolithic ceramics, continuous fiber MMC's are generally not machined using conventional machining techniques like milling and turning due to the hardness of the constituent fibers. Fibers present in the metal matrix pose another problem for machining of MMC's as any fiber breakage or pullout causes a reduction in the material properties. Furthermore silicon carbide (SiC) fibers and boron nitride interface are susceptible to oxidation and hence special care must be taken during machining.

Komanduri [**1997**] reported that in machining of a glass reinforced with continuous fibers of silicon carbide no cutting tool material could achieve a respectable tool life. The excessive tool wear and damage associated with machining of long fiber-reinforced metal matrix composites results in the process being uneconomical. It is clear that the presence of reinforcement makes MMCs different from monolithic materials due to incorporation of its superior physical properties. In addition, the amount and type of reinforcement introduce different properties in the strength and toughness of composites. Higher fiber/particulate reinforcement results in a reduction in the ductility of MMCs, causing harsh machining conditions.

Machining of particulate-reinforced metal matrix composites has been extensively studied experimentally to assess the linked tool wear, surface roughness and sub-surface damage. From the available literature on machining of MMCs it is obvious that the reinforcement material, type of reinforcement (particle or whisker), volume fraction of the reinforcement and matrix properties as well as the distribution of these particles in the matrix are the factors that affect the overall machinability of these composites. A correct selection of tooling and cutting conditions is therefore important. Cutting speed, feed and depth of cut have a similar effect on tool life and surface finish in machining of metal matrix compo- sites to those in machining of metals although some differences are noticeable due to the ceramic particles. The ceramic-reinforced particles tend to dislodge from the matrix and roll in front of the cutting tool, thereby ploughing through the machined surface and generating grooves on it [**Gallab 1998 and Manna 2003**]. The tool life decreases while the surface finish improves only slightly with an increase in cutting speed, since the tool temperature increases with cutting speed, thereby softening the tool material and consequently accelerating the diffusion wear [**Balazinski 2006 and Murugan 2008**]. On the other hand, feed rate negatively influences surface roughness, where the surface finish deteriorates with an increase in feed [**Davim 2003**]. Furthermore, feed has the largest effect on the damage observed in the sub-surface [**Dabade et al. 2009**], where larger feed results in more damage and a greater damage depth into the material. Dabade et al. [**2009**] concluded that the failure in the composite initiated along the voids generated around the SiC particles due to the high cutting forces observed at higher feeds. The voids join up to form micro-cracks and subsequent fracture along the shear band. On the other hand, feed tends to have less influence on tool wear. A high feed can reduce the tool wear rate due to an improvement in the conduction of heat from the cutting zone to the workpiece [**Balazinski 2006**]. Feed increases the flank wear but only marginally as compared to cutting speed. Depth of cut has a negative effect on the surface finish and the sub-surface damage. An increase in depth of cut decreases the quality of surface finish and the sub-surface damage. Further- more, depth of cut has a stronger effect on tool wear as compared to feed as shown in machining of an Al/SiC/15% composite with uncoated tungsten carbide tools [**Davim 2003**].

Palanikumar et al. [**2006]** demonstrated that the users of FRP are facing difficulties when machining it, because knowledge and experience acquired for conventional materials cannot be applied for such new materials, whose machinability is different from that of conventional materials. Thus, it is desirable to investigate the behavior of FRPs during the machining process. Everstine and Rogers [**1971**] have proposed an analytical theory of machining FRPs. In a classical study, they developed a theory of plane deformation of incompressible composites reinforced by strong parallel fibers.

Sakuma et al. [**1983**] and Bhatnagar et al. [**1988**] studied how the fiber orientation influence both the quality of the machined surfaces and tool wear. The machinability of composite materials is influenced by the type of fiber embedded in the composites, and more particularly by the mechanical properties. On the other hand, Rahman et al. [**1999**] demonstrated that the selection of cutting parameters and the cutting tool are dependent on the type of fiber used in the composites and which is very important in the machining process. Davim and Mata [**2004**] studied the influence of cutting parameters on surface roughness in turning glass-fiber reinforced plastics using statistical analysis. Ramulu et al. [**1994**] carried out a study on machining of polymer composites and concluded that higher cutting speeds give better surface finish.

Tekeyama and Lijma **[1988**] studied the surface roughness on machining of GFRP composites, according to them, higher cutting speed produce more damage on the machined surface. This is attributed to higher cutting temperature, which results in local softening of work material. They also studied the machinability of FRP composites using the ultra-sonic machining technique. According to Koing [**1985**] measurement of surface roughness in FRP is less dependable compared to that in metals, because protruding fiber tips may lead to incorrect results. Additional errors may result from the hooking of the fibers to the stylus. Palanikumar [**2008**] studied the effect of cutting parameters on surface roughness on machining of GFRP composites by polycrystalline diamond (PCD) tool by developing a second order model for predicting the surface roughness.

Vast amount of literatures is available on the machining of various FRPCs**,** while review on machinability of NFRCs is scarce. Although the experience from FRPC machining could be a starting point for machining of NFRCs, the wide variety of natural fibers and their distinct characteristics make it difficult to apply directly. [**Davim 2015, Liu et al. 2012 and Dandekar 2012**] The properties exhibited by the fibers complicate the manufacture of components from these materials. In particular, machining of NFRCs has been found difficult due to their mechanical anisotropy and inhomogeneity and the abrasive nature of the fiber reinforcement. Hence, the machining of NFRCs or FRPCs differs from the machining of homogenous materials such as metals [**Arola 2002**] and should be studied comprehensively. Although composite products are made to near-net shape, it still requires secondary manufacturing processes such as machining in order to meet assembly and dimensional requirements [**Festas et al. 2009**]**.** Machinability of NFRCs is strongly influenced by the type of fiber used in the composite and its properties such as mechanical and thermal. Hence, the selection of machining parameters and cutting tools used should take into account the type of fiber used as reinforcement or filler in a composite. By proper selection of these parameters, the machining process can produce the desired quality and integrity in the machined NFRC components [**Davim and Reis 2005**]. Also, understating of cutting mechanism is essential to analyze the machinability of

NFRCs. There are several manufacturing defects such as matrix imperfection, resin-starved area, resin-rich area, voids, cracks, and blisters and machining defects including de-bonding, delamination, fiber pull-out, and thermal damage associated with NFRCs [**Gohil et al. 2015**]. Several responses such as cutting force, cutting power, specific cutting force, tool wear, tool life, and surface roughness can be used to evaluate the machinability of materials. Although machinability is normally associated with workpiece material, there are other factors such as cutting conditions, tool material, tool geometry, and machining operations that influence machining.

Davim et al. [**2010**] summarized the several factors that affect the quality of the machined feature and its appearance. The several literatures surveyed for this review paper also revealed that most of the research on drilling of NFRCs has focused on delamination. Other quality parameters such as surface roughness, residual stresses, and roundness of the produced hole have not been given much attention. Future research should focus on these aspects of quality of hole. Drilling is one of the most important machining operations to facilitate the assembly operations of components produced from NFRCs. Although a number of approaches have been used for making drill in composites, conventional drilling is the most widely used method till date [**Salleh et al. 2013**]**.** Drilling of composite materials is considered to be a critical operation owing to their tendency to delaminate when subjected to cutting forces. In addition, other issues that affect the quality of the machined surface are the fiber/resin pull-out and poor surface roughness of the hole wall. Among the above issues associated with drilling, delamination appears to be the most critical. In order to overcome these issues, it is essential to develop a proper procedure and select appropriate cutting parameters [**Abrão et al. 2007**]**.**

Drilling of composites is much more difficult than metals, due to their relatively low sensitivity to heat damage and their weakness in the thickness direction. Composites are very susceptible to surface splintering and delamination, particularly if unidirectional material is present on the surface. Delamination factor is one of the direct methods of assessing the hole appearance while splintering is related to the sub-surface defect and the internal hole-surface quality. Both defects occur during drilling due to fiber pull-out and indicate the incompatibility of the composite components. Delamination can occur at both drill entrance and exit sides of the hole [**Cambell 2004**]**.** Measuring the damage of the natural fiber composites can be carried out either directly or indirectly. Direct measurements can be implemented using parameters such as delamination factor, damage width, surface roughness, and chip type produced. Indirect measurements involve assessment of the damage due to the thrust force, torque, or power generated during the machining operation. Roughness of produced surface, delamination degree, hole geometry are considered as indicators of the quality of produced holes. The main cause of delamination observed due to peel-up and push-out mechanisms associated with drilling composite laminates is the thrust force. The generated thrust force and torque is mainly affected by the variation of drill geometries, as the mechanism is different for various drill geometries [**Bajpai et al. 2015**].

Jayabal et al. [**2011**] produced hybrid composite material using polyester and short coir/glass fiber as reinforcing materials. They studied the drilling of this composite using a HSS twist drill. Machining results indicated that feed rate plays a major role on the responses (thrust force, torque, and tool wear) than the drill bit diameter and spindle speed. In contrast, Jayabal et al. [**2013**] proved that woven long coir fiber can enhance the mechanical properties of the composites and result in better quality drilled holes. Improved mechanical properties are possible because of the better bonding between the woven fibers and the matrix when compared to random or particulate reinforcements. For treated and untreated coir fibers, it was shown in thrust force and torque models that drill bit diameter, spindle speed, and feed rate are the significant factors that play a major role in determining the delamination area.

Balaji et al. [**2014**] found that treated woven coir mat exhibited low delamination when compared to non-woven coir reinforced polyester composites. Sakthivel et al. [**2015**] found that the optimized parameter to control thrust force in basalt/sisal fiber is drill bit diameter of 3 mm, speed of 300 rpm, and feed rate of 0.1 mm/rev. Velumani et al. [**2013**] developed mathematical model using response surface methodology (RSM), multilayer perceptron neural network (MLPNN), radial basis function networks (RBFN), and Elman neural network (ENN) methods to predict the thrust force and torque. It was found that MLPNN technique is one of the very simple algorithms that yielded better results than all other techniques used in the study.

Chandramohan and Marimuthu [**2011**] observed that the torque increases with the increase in the fiber volume fraction. This is because increasing the fiber volume fraction increases the static strength resulting in the increase of the resistance of the composite to drilling. The higher resistance exhibited by the composite leads to higher thrust force and torque. The result also indicated that the torque decreases when increasing the cutting speed. Similar trend of increase in thrust force with the increase in fiber volume fraction and decrease with an increased cutting speed was observed by Athijayamani et al. [**2010**]. They found that composites with 30 % roselle and sisal hybrid fiber content and 8 hour alkali treatment of fibers resulted in a better dimensional accuracy than did other compositions and treatment times during drilling. Babu et al. [**2012**] found that delamination is minimum during drilling of hemp fiber reinforced composite. In contrast, the jute fiber reinforced composite always produced higher delamination factor, which indicates higher damage in the composite laminate. Overall, it is observed that the delamination factor of drilled NFRCs is in some cases better than those of glass fiber reinforced composite.

Abilash and Sivaprakash [**2013**] reported that the influence of cutting speed on peel-up delamination is low when compared to push-out delamination while the peel-up and push-out delamination of woven bamboo/polyester composite decreased with increasing cutting speed. The size of delamination increases with increase in feed, as a result of increase in thrust force and drill diameter. They also showed that the axial thrust force exerted by twist drill is the major cause for delamination. The most popular way of reducing delamination damage during machining is to support the bottom plies of the laminates. Lower thrust force and torque are preferred for better drilling accuracy. According to Bajpai et al. [**2015**], this can be achieved using parabolic drills as compared to four-facet and step drills. That can be attributed to the point geometry of the chisel edge which makes parabolic drill an attractive tool for making holes in nettle/PP composite laminates. Highest values of thrust force and torque were generated when using step drills.

The machinability of chopped date palm reinforced polypropylene bio-composites was experimentally investigated by the authors recently. Drilling was performed using twist drill of diameters (4 to 8 mm), spindle speed (1000 to 3000 rpm), and feed rate (50 to 250 mm/min). The results demonstrated that the drill size significantly influences the delamination among the cutting parameters. The optimal setting of the input variables shows that a combination of moderate values for drill diameter, low feed rate, and low spindle speed leads to a minimum value of delamination. It was also observed that the induced delamination was minimal, and so it can be concluded that chopped date palm reinforced polypropylene bio composites are promising NFRCs for industrial applications.

Machining operations are vital for the production of composite materials so that they could be employed in industrial applications. After drilling operation, end-milling is one of the primary machining processes widely used for producing precision pockets and slots in various materials. However, milling operations induce damage to the surface in the form of delamination, micro-cracks, fiber pull-out, and matrix burning, ultimately affecting the performance of the components. This issue of damage needs to be addressed so that the scope of application of NFRCs could be widened benefitting the entire NFRC user community [**Babu et al 2013**]**.** Attempts have been made to analyze various machining parameters using optimization and artificial intelligence so as to reduce the number of experiments required for selecting the optimum machining conditions.

Vinayagamoorthy and Rajeswari [**2012**] fabricated a new composite plate made of isopthalic polyester as the matrix and natural jute as the fiber using hand layup technique. They machined this plate using a four-fluted HSS end-mill, and it was found that speed and depth of cut are the most influencing factors on thrust force whereas speed, feed, and depth of cut are the predominant parameters influencing torque. High speed, high feed, and medium depth of cut are the optimum machining conditions to obtain optimum thrust force whereas high speed, low feed, and low depth of cut are the optimum conditions for optimum torque. The feed rate has to be balanced in order to get lower values of both thrust force and torque.

Babu et al. [**2013**] evaluated the cutting parameters (cutting velocity and feed rate) and the influence of the fibers on delamination factor (F_d) and surface roughness (R_a) during end-milling. The feed rate and cutting speed have been found to be the dominant factors contributing to the delamination factor (F_d) and surface roughness (R_a). Generally, the use of high cutting speed and low feed rate is favored to reduce delamination in milling of hemp, jute, banana, and glass fiber reinforced polyester. Harun et al. [**2015**] also found that the feed rate and the cutting speed are the dominant factors that influence the surface roughness during milling of kenaf fiber reinforced composites. High cutting speed and low feed rate resulted in lower surface roughness for milling kenaf fiber reinforced composites. The machined surface of NFRCs is significantly dependent on the fiber stiffness and interface bonding.

Chegdani et al. [**2015**] focused on the influence of natural fiber types on tribological behavior during profile milling process. Three types of short natural fiber (bamboo, sisal, and Miscanthus) reinforced polypropylene composites were investigated. The bamboo fiber reinforced plastics exhibited high contact stiffness, and smoother surface finish was obtained after machining. Scanning electron microscope (SEM) observations showed that the natural fiber shearing mechanism is not purely ductile and its action is strongly dependent on the fiber type. This is due to the intrinsic mechanical properties of natural fibers and the adhesion properties between elementary fibers themselves. It was also noticed that the viscoelastic behavior of natural fiber provokes an important fiber deformation and then interface break during the contact with the milling tool. This generates fiber extremities that project out of the machined surface resulting in higher surface roughness values. As discussed earlier, since most NFRC components are produced by net shape manufacturing, there is not much scope for turning except for finishing requirements. Hence, in the open literatures, hardly a few researches work on turning of NFRCs are available.

Zajac et al. [**2014**] analyzed machining of wood plastic composite (WPC) consisting of more than 70 % wood particle and the rest polyethylene matrix. During the machining, two parameters were changed that is rotation speed and feed rate. The main problem faced during the machining of WPC is inhomogeneity leading to differences in the average value of roughness measured at three random spots on the surface. Higher tool nose radius, lower feed rates, and higher cutting speeds are recommended parameters for producing better surface roughness (R_a). Inhomogeneity of composite material can be eliminated by using particulate fillers or by increasing the coupling agent.

Somsakova et al. [**2012**] investigated the surface roughness of WPC after turning. Turning was performed at constant speed and fixed depth of cut. It was observed that the surface roughness decreased when the feed rate was decreased. For better quality of surface roughness, it is recommended to use larger tool nose radius or application of a tool with a linear cutting edge.

2.4 Optimization of Machining Parameter and Surface Roughness in Machining

Process models have often targeted the prediction of fundamental variables such as stresses, strains, strain rate, temperature, etc. but to be useful for industry these variables must be correlated to performance measures and product quality (accuracy, dimensional tolerances, finish) [**Arrazola et al. 2013**]. Recent review papers on machining show that the most widely machining performances considered by the researchers are surface roughness followed by machining/production cost and material removal rate [**Yusup et al. 2012**]**.** Recently, the researchers have started to analyze and optimize the power consumption in machining [**Aggarwal et al. 2008, Negrete 2013 and Hanafi et al. 2012**]. Energy savings up to 6-40% can be obtained based on the optimum choice of cutting parameters, tools and the optimum tool path design [**Newman et al. 2012**]. The various predictive modeling techniques used to determine optimal or near-optimal cutting conditions are statistical regression analysis, response surface methodology and artificial neural network. The widely used modeling technique is response surface methodology (RSM) because it offers enormous information from even small number of experiments [**Pradhan 2013**]. In addition, it is possible to analyze the influence of independent parameters on performance characteristics. The various authors have used Taguchi method, RSM, genetic algorithm, grey relation analysis, *etc.* as optimization techniques.

Bhushan [**2013**] used RSM and desirability analysis to determine the optimal machining parameters during machining of AA7075-15 wt.% SIC using tungsten carbide cutting tool to get minimum power consumption and maximum tool life. The study revealed that cutting speed is the most significant parameter followed by depth of cut, feed and nose radius.

Camposeco-Negrete [**2013**] applied Taguchi methodology and ANOVA to optimize the cutting parameters during turning of AISI 6061 T6 under roughing condition to achieve minimum energy consumption and minimum surface roughness. The results of this research show that feed rate (87.79%) is the most significant factor followed by depth of cut (6.59%) and cutting velocity (5.18%) for minimizing energy consumption.

However, the objective function was not multi-objective; therefore, the power consumption and surface roughness were considered in isolation to each other.

Hanafi et al. [**2012**] applied grey relational theory and Taguchi optimization methodology to optimize the cutting parameters in machining of PEEK-CF30 using TiN tools under dry conditions. The objective of optimization was to achieve simultaneously the minimum power and best surface quality. The obtained results revealed that depth of cut (44.54%) is the most influential parameters followed by cutting speed (36.14%) and feed rate (6.39%). Aggarwal et al. [**2008**] used RSM and Taguchi's technique to investigate the effect of cutting speed, feed, depth of cut, nose radius, and cutting environment during turning of AISI P20 tool steel on the power consumption. Results show that the cutting speed is the most significant factor followed by depth of cut and feed.

Fratila and Caizar [**2011**] applied Taguchi methodology to optimize the cutting conditions in face milling while machining $AlMg_3$ with high speed steel (HSS) tool under semi finishing conditions to get the best surface roughness and the minimum power consumption. The appropriate orthogonal array, signal to noise ratio and Pareto analysis of variance (ANOVA) were employed to analyze the effect of the mentioned parameters on the surface roughness. The results indicate that the optimum cutting conditions to minimize power consumption are minimum depth of cut, minimum feed rate, minimum cutting speed and maximum lubricant flow rate.

Yan and Li [**2013**] presented a multi-objective optimization method based on weighted grey relational analysis and RSM to optimize the cutting parameters in milling process during dry cutting of medium carbon steel with carbide tool to achieve the minimum cutting energy, maximum material removal rate and minimum surface roughness. The results indicate that width of cut is the most influencing parameter followed by depth of cut, feed rate and spindle speed. The experimental results indicate that RSM and grey relational analysis are very useful tools for multi-objective optimization of cutting parameters.

Sarıkaya and Güllü, [**2014**] developed the mathematical models using RSM to study the effect of cooling condition, cutting speed, feed rate and depth of cut on average surface roughness (R_a) and average maximum height of the profile (R_z) during turning of

AISI 1050 steel. ANOVA results showed that feed rate was the most influencing factor with a contribution of 68.68%, followed by cooling conditions with a contribution of 16.98% on R_a. R_z was influenced by feed rate with a contribution of 77.50%. Confirmation experiments showed that the percentage deviation between the actual and experimental data is between 2.72% and 7.14%.Campatelli et al. [**2014**] utilized the RSM to analyze the effect of cutting speed, feed rate, radial and axial depth of cut on energy consumption during milling of carbon steel. The optimal value of the radial engagement to minimize the specific energy related to the efficiency of the cutting was achieved at 1mm and the feed per tooth shows a 0.12 mm/tooth optimal value.

Sharma et al. [**2008**] investigated surface roughness of adamite and measured various forces along with developing an artificial neural network (ANN) model during turning operation. Cutting speed, feed, depth of cut and approaching angle were set as the input parameters whereas feed force, thrust force, passive force and surface roughness were the chosen as the output parameters. It was found that cutting force (F_c) showed an increasing trend with the increase in approaching angle, feed and depth of cut whereas it showed a decreasing trend with speed. Passive force (F_p) increased with increase in depth of cut, speed and feed whereas it showed a decreasing trend with increase in approaching angle. The depth of cut exhibited maximum influence on passive force (F_p) in comparison to other machining parameters. Feed force (F_f) showed increasing trend with all variables i.e. approaching angle, speed, feed and depth of cut. The depth of cut exhibited maximum influence on the feed force (F_f). The developed neural network model could predict R_a with moderate accuracy but the model was able to predict the above mentioned three forces with high accuracy.

Palanikumar et al. [**2007**] found that feed rate has greater influence on surface roughness parameter (R_a), followed by cutting speed and % volume fraction of SiC in machining of Al/SiC particulate composites. Nalbant et al. [**2007**] optimized the cutting parameters for turning of AISI 1030 steel bars by using the Taguchi method. They considered the center line average (R_a) only. The use of greater insert radius, low feed rate and low depth of cut are recommended to obtain better surface finish for the specific test range.

Singh et al. [**2007**] developed mathematical model for R_a and optimized the tool geometry and cutting parameters for hard turning using genetic algorithm. Zhong et al. [**2006**] predicted surface roughness heights R_a and R_t of turned surface using neural network. Sahin and Motorcu [**2005**] developed mathematical model of surface roughness parameter R_a in turning of mild steel with coated carbide tools using RSM. They concluded that feed rate is the main influencing factor on the surface roughness. Noordin et al. [**2004**] described the performance of coated carbide tools using response surface methodology when turning AISI 1040 mild steel. They found that feed rate is the most significant parameter influencing the surface roughness R_a and tangential force. Taguchi method was used by Yang and Tarang [**1999**] to find the optimal cutting parameters for turning operations. Choudhury and El Baradie [**1997**] had predicted surface roughness parameter R_a using RSM when turning high strength steel. Lin **[2004**] used grey relational analysis to optimize turning operations with multiple performance characteristics, viz., cutting force and surface roughness Ra in turning operations.

2.5 Objectives of the Research

Objectives of the present research are:

i. Development of a composite material by reinforcing alkaline treated banana fibre with epoxy resins to evaluate the mechanical properties such as tensile strength, impact strength, flexural strength and hardness of the fabricated composite.

ii. Systematic experimental study on the role of compressed cooling air on the machinability characteristics of banana fibre reinforced epoxy composite at different cutting velocities and feeds in respect of surface roughness.

iii. Develop a model to predict surface roughness using an Artificial Neural Network and to optimize the machining parameter while machining banana fibre reinforced epoxy compositeunder compressed cooled air condition.

2.6 Scope of the thesis

Chapter 1 presents the brief description of composite materials, different matrix materials that can be used in a fiber reinforced polymer. Furthermore, it also highlights the evolution of natural fiber reinforced polymer and its varieties of application.

Chapter 2 presents the main goals and objectives of machining operation, works that have been previously done on FRP composites keeping their mechanical properties on thoughts, complications associated with machining a FRP material, the techniques that are used to model surface roughness of a machined surface. This chapter also provides the main scope of this research.

Chapter 3 presents the development of the fiber reinforced composite material where two different fibers i.e. alkaline treated banana fiber and glass fiber have been used to reinforce the same matrix material. Epoxy has been used as the matrix material in this research work.

Chapter 4 deals with the experimental investigation and findings that have been achieved by carrying out turning operation on the developed fiber reinforced composite material under both dry and compressed air cooling condition. It further illustrates the variation of average surface roughness and main cutting force with under both machining environments.

Chapter 5 explains the theory of response surface methodology (RSM), network structure, learning rule and adaptive transfer fuction of artificial neural network (ANN). In addition, the chapter also demonstrate the modeling of surface roughness using RSM and ANN of the developed composite under compressed air cooling condition. The chapter deals with desirability function analysis to find out optimum machining conditions and concludes with the efficacy of the developed ANN model for predicting surface roughness.

Chapter 6 contains the thorough discussions on the experimental results considering the machined surface roughness, main cutting force and artificial neural network model for predicting surface roughness. The reduction of main cutting force and surface roughness due to the usage of compressed air cooling are also presented in tabulated form. This chapter also contains the discussion regarding the modeling of surface roughness of banana fiber reinforced epoxy. Lastly, a summary of major contributions, recommendation for the future work and references are provided.

Chapter-3

Materials and Methods

3.1 Development of Alkaline Treated Banana Fiber Reinforced Composite

Major constituents in a FRP composite are fiber and the matrix. The matrix acts as a binder for the reinforcing agents. Similar to that, in a natural fiber based composite material, fibers and the matrix are the main components. Mechanical and other physical properties of banana fibers are influenced by their growing conditions, processing technique, fiber types, by the fineness of the fiber and sample test-length. Although, as with most of the other plant-based natural fibers, cellulose forms the main structural component of jute, the non-cellulosic components e.g., lignin and hemicellulose, also play an important part in determining the characteristic properties of the fibers.

Akmal Hadi Ma Radzi., et al., [**2011**] have done a work in which the banana fiber is reinforced with polylactic acid (PLA) matrix. The extracted fibers treated with acetone, NaOH and distilled water containing little hydrochloric acid. The effects of fiber volume ratio on mechanical properties were discussed. Thiruchitrambalam., et al., [**2009**] observed the improvement of mechanical properties of banana/ kenaf polyester hybrid composites using sodium Lauyrl sulphate (SLS) and it has been compared with NaOH surface treatment. The treatment of 10% SLS for 30 minutes was significantly increased the tensile, flexure and impact strength. The improve lies marginally 10-20%.

In this research, the materials used in this work are Banana fiber, Epoxy resin and Epoxy hardener. Banana fiber is collected from bark of the banana plant. Banana fiber is used as reinforcement material while epoxy is used as matrix materials. The extracted banana fiber were subsequently sun dried for eight hours to remove the water present in the fiber. Surface modification of banana fibers were conducted using NaOH treatment by immersing the fiber in sodium hydroxide (10 g/l) solution for four hours to improve the mechanical properties of treated banana fiber reinforced composite. After the alkaline treatment the fibers were rinsed with alcohol, followed by water and sun-dried for 8 hours. SEM analysis of treated fiber is shown in Fig. 3.1

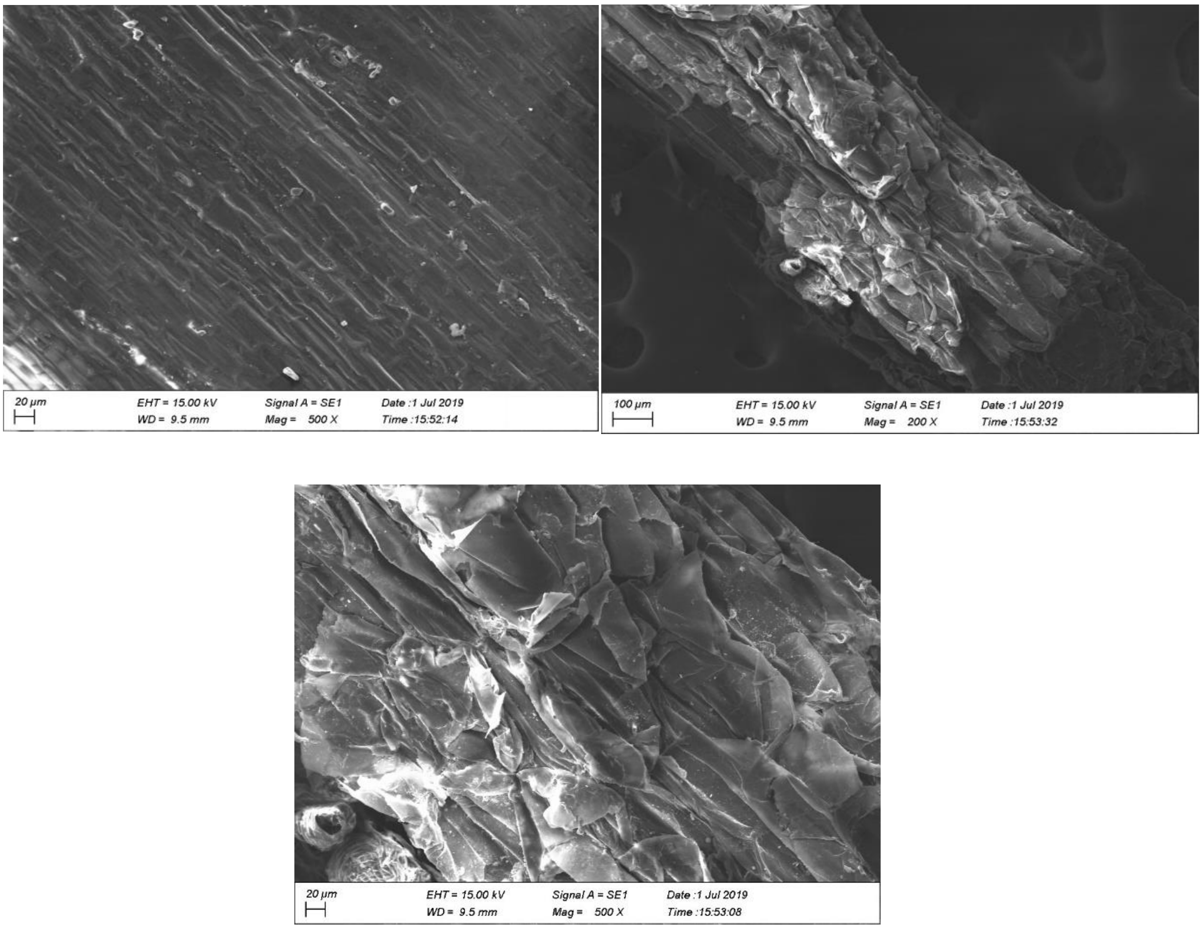


Fig. 3.1 SEM analysis of treated Banana fiber

Many techniques are available in industries for manufacturing of composites such as compression molding, pultruding, hand layout and resin transfer molding. Since hand, layout technique is one of the simplest and easiest methods for manufacturing; it has been used to fabricate the composite specimen for testing purpose. Hand layout is suitable due to its simple equipment and tooling that are relatively less expensive than other manufacturing process.

The pseudo-stem banana woven fabric reinforced epoxy composite was prepared by the hand lay-up method. The fibers are extracted from banana stems by hand and dried in sunlight for eight hours until all the moisture is removed from the fiber. The dried fibers are made in the configuration of random longitudinal fabric. Matrix material (epoxy resin, grade 3554A and hardener grade 3554B) were prepared in a portion of 4 parts of epoxy resin and 1 part of hardener by volume. These two materials were thoroughly mixed and stirred at low speed until it become uniform. The matrix material was poured into the mold slowly in order to avoid air trapping. The mixture was left for 2 hours so that it becomes a little tacky. After that, the banana fiber woven fabric was laid on the matrix layer, which was covered by another layer of matrix by pouring the mixture slowly onto the surface of the fiber woven fabric. The three layered composite was cured at room temperature until it was dried. The same steps were used to make an hybrid glass and banana fiber reinforced epoxy material.

3.2 Properties Testing of the Developed Composite

Specimen of different dimension was prepared for testing purpose as shown in Fig 3.2. A rectangular composite specimen were made as per ASTM D638M to measure the tensile properties. Length, width and thickness of the specimen were 165, 20 and 5 mm respectively. It shows that 30% weight reinforcement of alkaline treated banana fiber in composite yields to a tensile strength of 55.34 N/mm^2 while 1:5 ratio of glass and banana fiber hybridization gives a tensile strength of 62.8 N/mm^2

For flexural testing, a specimen was made having dimension of 100 × 12 × 5 mm. Flexural strength was found to be at 59.4 N/mm^2 and 62.3 N/mm^2 respectively for 30% weight fraction of banana fiber and hybrid fiber. Thereafter, dimension of 65 × 15 ×5 mm specimen was prepared for testing of impact strength. For 30% weight fraction of banana fiber and hybrid fiber, impact strength was 92.3 J/m^2 and 96.4 J/m^2 respectively.


(a)


(b)


(c)

Fig. 3.2 Specimen of banana fiber reinforced epoxy composite for (a) Tensile test (b) Flexural test and (c) Impact test

A cylindrical bar of composite material was developed by casting the raw materials i.e. Banana fiber, epoxy and epoxy hardener together in a cylindrical mold. The developed work material is shown in Fig. 3.3.

Fig. 3.3 Developed work material

Chapter-4

Experimental Investigation

4.1 Experimental Procedure and Conditions

Composite materials are widely used in diverse applications, and extensive research has been performed to understand the mechanical behavior of such material and develop design procedures for taking maximum advantage of their properties. However, being non-homogenous, anisotropic and reinforced with very abrasive fibers, these materials are difficult to machine. Significant damage to the work piece may be introduced and high wear rates of the tools are experienced. Traditional machining methods such as drilling, turning, sawing, routing and grinding can be applied to composite materials using appropriate tool design and operating conditions. Generally, composites armored with glass-fiber or other materials, with a unidirectional orientation, are used on a large scale at the production of structures, piece binding elements, electrical isolation tapes because they have good behavior to mechanical stresses and a high mechanical resistance to weight ratio.From the point of view of the advantages offered by these materials are high toughness, relatively high temperature resistance, and good mechanical resistance, high resistance to corrosion and wear, the question of why these materials are used on such a small scale in industry is raised.

Compressed air cooling has quite e a few benefits in case of machining of composites in compare to dry cutting machining environment. Different factors like fiber and matrix properties, fiber angle, and orientation of the fiber and adhesion properties between the fibers have impact on the behavior of the composite. Keeping the delamination damage factor in mind, turning operation was done on the developed polymer composite material using different combinations of cutting speed, feed rate and depth of cut. Selected parameters was varied along with dry and compressed air cooling machining condition. As machining of polymer composite under compressed air cooling condition is different from other metals due to its anisotropic nature and different mechanical properties, it has steered us to conduct the experiment under this condition. The machine tool used during the machining investigation was KL-3280C/2000 (Sunlike Engine Lathe). The specifications of the machine tools were- 50 Hz, 1440 rev. /min., 7.5 kW, 420 V and 13.9 A. The experiment was designed using response surface methodology. Central composite design method was used due to accuracy in designing an experiment. Cutting speed, feed rate and depth of cut was considered as input parameters while average surface roughness and cutting force was measured as resultant output parameter. RSM designed combinations of all the input parameters were replicated for both dry and compressed air cooling cutting environment. Cutting conditions and process parameters of the experimental investigation are listed on the Table 4.1.

From literature review, it was found that the coated carbide insert performed much better than uncoated carbide based on the manufactured product quality. As composites have a very low wear resistance, high-speed steel cutting tool should not be used while machining composites. Keeping all those parameters in mind SNMG coated tungsten carbide (WC) has been chosen as the tool material for machining Banana Fiber reinforced epoxy composite under both dry and compressed air cooling condition. Fig. 4.1 shows the photographic view of the experimental setup. Another important thing to remember is the accuracy of the whole compressed cooling process depends on the delivery of cooled air in the chip- tool and work- tool interface. The nozzle position owing to deliver-cooled air onto the chip- tool interface is shown in Fig. 4.1. Table 4.1 presents the experimental conditions for the machining investigation.

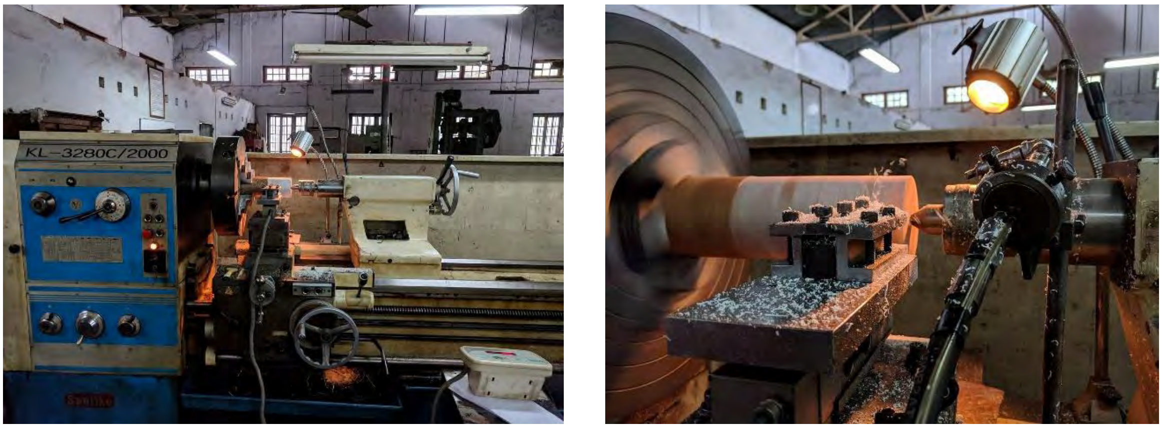


Fig. 4.1 Photographic view of experimental setup

Table 4.1 Experimental Conditions

Machine Tool	**:** KL-3280C/2000 (Sunlike Engine Lathe, 7.5 kW).
Work Material	**:** Glass Fiber reinforced Epoxy Composite **:** Banana Fiber reinforced Epoxy Composite
Dimension	**:** 300 mm length and 100 mm diameter.
Cutting Insert	**:** Titanium nitride coated tungsten carbide (SNMG)
Cutting Tool Geometry	**:** -6°, -6°, 6°, 6°, 15°, 75°, 0.8 (mm)
Process Parameters	
Cutting Speed, V_c	**:** 55 m/min and 154 m/min
Feed, S_o	**:** 0.08 mm/rev and 0.14 mm/rev
Depth of cut, t	**:** 0.2 mm and 0.8 mm
Machining Environment	**:** Dry and Compressed air cooling (Air pressure- 8 Bar)

4.2 Experimental Results

By using RSM designed machining combinations, straight turning operations was conducted on the developed polymer composite under dry and compressed air cooling condition to measure average surface roughness and main cutting force. Main cutting force was measured using a strain gauge dynamometer and the charge amplifier in kg unit displayed the magnitude of the main cutting force. Afterwards, average surface roughness was measured using a sampling length of 10 mm. Resultants output values with respect to different combination of input parameter for both the developed composites are shown in Table 4.2 and Table 4.3

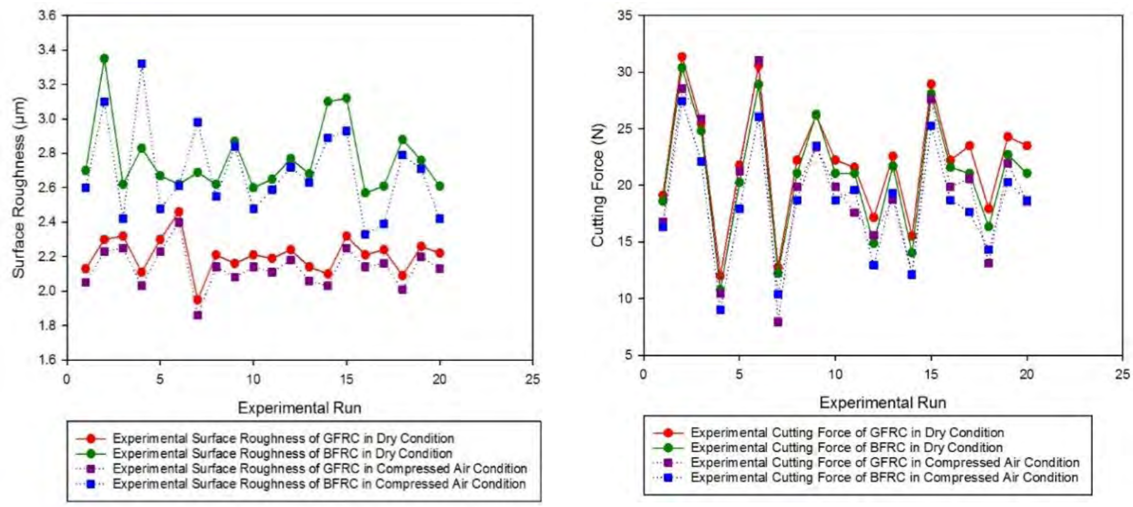
Table 4.2 Experimental design with input variables and measured responses for banana fiber reinforced epoxy composite

Process Parameters			Environment			
T (mm)	V_c (m/min)	S_o (mm/rev)	Dry Condition		Compressed air condition	
			R_a (μm)	P_z (N)	R_a (μm)	P_z (N)
0.5	110	0.08	2.70	18.61	2.60	16.33
0.8	154	0.14	3.35	30.39	3.10	27.46
0.8	55	0.08	2.62	24.81	2.42	22.14
0.2	55	0.08	2.83	10.77	3.32	9.00
0.5	55	0.12	2.67	20.26	2.48	17.93
0.8	55	0.14	2.62	28.92	2.61	26.08
0.2	154	0.08	2.69	12.24	2.98	10.37
0.5	110	0.12	2.62	21.07	2.55	18.70
0.8	154	0.08	2.87	26.27	2.84	23.51
0.5	110	0.12	2.60	21.07	2.48	18.70
0.5	110	0.12	2.65	21.07	2.59	19.60
0.2	55	0.14	2.77	14.88	2.72	12.94
0.5	154	0.12	2.68	21.72	2.63	19.31
0.2	110	0.12	3.10	14.05	2.89	12.13
0.8	110	0.12	3.12	28.09	2.93	25.27
0.5	110	0.12	2.57	21.60	2.33	18.70
0.5	110	0.12	2.61	21.07	2.39	17.66
0.2	154	0.14	2.88	16.35	2.79	14.32
0.5	110	0.14	2.76	22.72	2.71	20.28
0.5	110	0.12	2.61	21.07	2.42	18.70

The variation of experimental surface roughness and cutting force while machining Glass Fiber Reinforced Composite (GFRC) and Banana Fiber Reinforced Composite (BFRC) under both dry and compressed air condition is shown in Fig. 4.2. From (a) it is clearly observed that the surface roughness of GFRC is less than the surface roughness of BFRC in both dry and compressed air condition, which demonstrates that GFRC gives preferable surface finish over BFRC. However, from (b) it is noticed that the cutting force in dry condition overlapped with each other for both GFRC and BFRC. There is no significant change for both materials in dry condition. On the contrary, in compressed air condition, the cutting force of BFRC seems to diminish in most of the cases comparing to GFRC.

Table 4.3 Experimental design with input variables and measured responses for glass fiber reinforced epoxy composite

Process Parameters			Environment			
			Dry Condition		Compressed air condition	
t (mm)	V_c (m/min)	S_o (mm/rev)	R_a (µm)	P_z (N)	R_a (µm)	P_z (N)
0.5	110	0.08	2.13	19.13	2.05	16.78
0.8	154	0.14	2.30	31.35	2.23	28.55
0.8	55	0.08	2.32	25.40	2.25	25.88
0.2	55	0.08	2.11	12.00	2.03	10.45
0.5	55	0.12	2.30	21.80	2.23	21.26
0.8	55	0.14	2.46	30.57	2.40	31.04
0.2	154	0.08	1.95	12.78	1.86	7.96
0.5	110	0.12	2.21	22.23	2.14	19.88
0.8	154	0.08	2.16	26.18	2.08	23.39
0.5	110	0.12	2.21	22.23	2.14	19.88
0.5	110	0.12	2.19	21.60	2.11	17.60
0.2	55	0.14	2.24	17.16	2.18	15.61
0.5	154	0.12	2.14	22.58	2.06	18.77
0.2	110	0.12	2.10	15.53	2.03	12.17
0.8	110	0.12	2.32	28.93	2.25	27.59
0.5	110	0.12	2.21	22.23	2.14	19.88
0.5	110	0.12	2.24	23.50	2.16	20.60
0.2	154	0.14	2.09	17.94	2.01	13.12
0.5	110	0.14	2.26	24.30	2.20	21.94
0.5	110	0.12	2.22	23.50	2.13	18.60



(a) (b)

Fig. 4.2 Variation of experimental (a) Surface Roughness (b) Cutting Force while machining GFRC and BFRC under both dry and compressed air condition

Chapter-5

Mathematical modeling by RSM and ANN

5.1 Mathematical Modeling by Response Surface Methodology

Response Surface Methodology (RSM) is a collection of mathematical and experimental techniques that requires sufficient number of experimental data to analyze the problems and to develop mathematical models for several input variables and output performance characteristics. Khuri and Mukhopadhyay mentioned in their research that, RSM model can be utilized to state the degree of correlation between one or more response and some selected control variables. Main purpose is to determine through goodness of fit; statistical significance of the factors connected with a particular response and to determine the optimum settings within the higher or lower level of control variables to minimize or maximize the response of interest. **[2010].** The output response are proposed using the fitted second-order polynomial regression model which is called quadratic model. The quadratic model of Y can be written as follows:

$$Y = a_0 + \sum_{i=1}^{k} a_i x_i + \sum_{i=1}^{k} a_{ii} x_i^2 + \sum_{i=1}^{k} a_{ij} x_i x_j \qquad (1)$$

Here, Y represents the response and x_i,x_j are the independent variables.

5.1.1 Modeling of Surface roughness and Cutting Force of Banana Fiber Reinforced Composite

ANOVA (Analysis of variance) for the response surface models were conducted in this study for dry condition, Sum of squares (SS), degree of freedom (df), mean square (MS) and prob>F for all the factors along with their square and interaction term are shown in ANOVA table. SS in the sum of the squared deviations from the mean and MS is the variance associated with each particular term. The variance is calculated by dividing SS by df. For the purpose of comparison between the variance of a particular term with residual variance, F-value is calculated by dividing MS for that term by MS for the residual. The large F value indicates the greater likelihood thet the differences between the means are due to real effects rather than chances alone. A term that has a Prob>F value less than 0.05 would be considered as statistically significant model. R squared (R^2), adjusted R squared (adj R^2), predicted R squared (pred R^2) and adequate precision are calculated for the purpose of deep calculation of the performance of the involved model. R^2 is known as coefficient of determination, which helps to measure success of predicting the dependent variable from the independent variables. **[nagerkelke]** Model that acquire larger R^2 values have better capability to make accurate predictions. Adequate precision measures signal to noise ratio, usually a greater than four is desired to achieve a significant model for optimization. The comprehensive statistics of the experimental measurements are stated in Table 5.1

Table 5.1 Design Summary of the responses of BFRC for dry condition

Response	Name	Units	Obs.	Min	Max	Mean	Std. Dev.	Ratio	Model
R1	R_a	µm	20	2.57	3.35	2.77	0.2083	1.30	Quadratic
R2	P_z	N	20	10.77	30.39	20.85	5.34	2.82	Quadratic

ANOVA (Analysis of variance) conducted for average surface roughness (R_a) for dry cutting environment which is shown in Table 5.2. Measurements implies that statistical significance of the quadratic model as F-value of the model is 5.34 and Prob>F is less than 0.05. As per the results, V_c and S_o are the most significant factors associated with the development of the model. Similarly, ANOVA conducted for cutting force is shown in Table 5.3 where F value of the model is 2438.63 and Prob>F is less than 0.001. The response surface quadratic equation in terms of actual factors for surface roughness and main cutting force are stated in eqn. 2 and 3.

Table 5.2 ANOVA for R_a while machining BFRC under dry condition

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	0.6826	9	0.0758	5.34	0.0076	significant
t	0.0070	1	0.0070	0.4947	0.4979	
V_c	0.0856	1	0.0856	6.03	0.0340	significant
S_o	0.0424	1	0.0424	2.98	0.1148	
$t \times V_c$	0.1257	1	0.1257	8.84	0.0140	significant
$t \times S_o$	0.0141	1	0.0141	0.9921	0.3427	
$V_c \times S_o$	0.0573	1	0.0573	4.04	0.0723	
t^2	0.2991	1	0.2991	21.05	0.0010	significant
V_c^2	0.0237	1	0.0237	1.67	0.2252	
S_o^2	0.0034	1	0.0034	0.2390	0.6355	
Residual	0.1421	10	0.0142			
Lack of Fit	0.1387	5	0.0277	40.79	0.8065	not significant
Pure Error	0.0034	5	0.0007			
Corrected Total	0.8247	19				

Table 5.3 ANOVA for P_z while machining BFRC under dry condition

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	541.66	9	60.18	2438.63	< 0.0001	significant
t	491.39	1	491.39	19910.73	< 0.0001	significant
V_c	5.36	1	5.36	217.25	< 0.0001	significant
S_o	42.24	1	42.24	1711.72	< 0.0001	significant
$t \times V_c$	0.0000	1	0.0000	0.0005	0.9828	
$t \times S_o$	0.0000	1	0.0000	0.0005	0.9818	
$V_c \times S_o$	0.0000	1	0.0000	0.0005	0.9822	
t^2	0.0019	1	0.0019	0.0775	0.7864	
V_c^2	0.0017	1	0.0017	0.0689	0.7983	
S_o^2	0.0011	1	0.0011	0.0448	0.8367	
Residual	0.2468	10	0.0247			
Lack of Fit	0.0127	5	0.0025	0.0543	0.9969	not significant
Pure Error	0.2341	5	0.0468			
Corrected Total	541.91	19				

$$R_{a\,(BFRC\text{-}Dry)} = 3.4124 - 5.09758 \times t - 0.00213281 \times V_c + 6.24837 \times S_o + 0.00842908 \times t \times V_c + 5.57456 \times t \times S_o + 0.068059 \times V_c \times S_o + 3.66416 \times t^2 - 3.84554e\text{-}05 \times V_c^2 - 58.8812 \times S_o^2 \quad (2)$$

$$P_{z\,(BFRC\text{-}Dry)} = -2.67298 + 23.6784 \times t + 0.0168818 \times V_c + 89.7704 \times S_o - 8.24885e\text{-}05 \times t \times V_c + 0.172678 \times t \times S_o + 0.00102263 \times V_c \times S_o - 0.293043 \times t^2 - 1.02921e\text{-}05 \times V_c^2 + -33.5856 \times S_o^2 \quad (3)$$

Fig. 5.1 and Fig. 5.2 illustrates 3D response surface plots of average surface roughness and main cutting force in terms of cutting speed, feed rate and depth of cut.

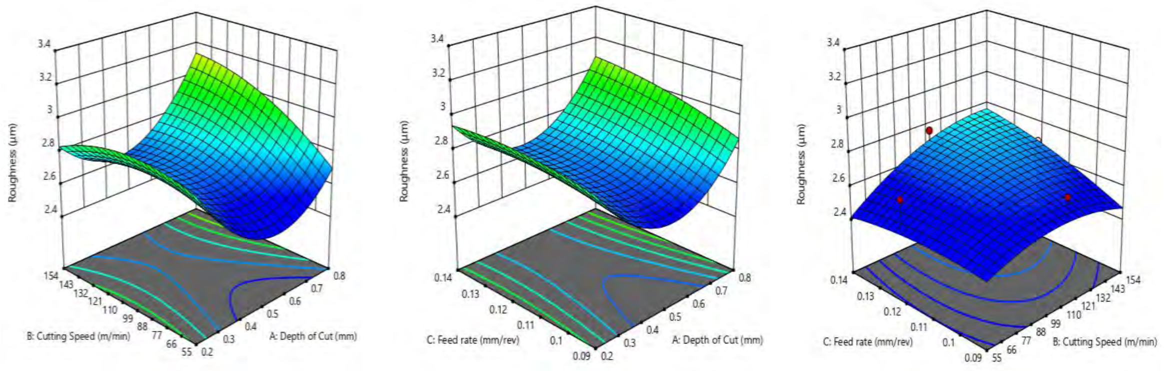


Fig. 5.1 Surface Plots of R_a while machining BFRC under dry condition

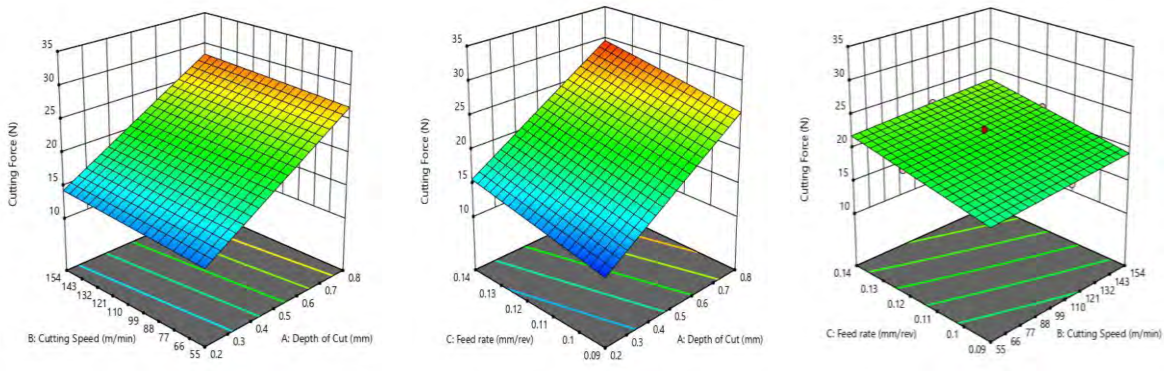


Fig. 5.2 Surface Plots of P_z while machining BFRC under dry condition

Modeling of Surface roughness and Cutting Force of Banana Fiber Reinforced Composite under Compressed air has also been performed where Table 5.4 represents comprehensive statistics of the experimental measurements for compressed air cooling condition.

Table 5.4 Design Summary of responses of BFRC in compressed air condition

Response	Name	Units	Obs.	Min	Max	Mean	Std. Dev.	Ratio	Model
R1	R_a	µm	20	2.33	3.32	2.69	0.297	1.42	Quadratic
R2	P_z	N	20	9	27.5	18.46	5.02	3.05	Quadratic

ANOVA for average surface roughness and main cutting force under compressed cooling condition are shown in Table 5.5 and 5.6. Measurements implies statistical significance of the quadratic model as F-value of the model is 8.98 and Prob>F is less than 0.05. As per the results, t, ($t \times V_c$), ($t \times S_o$) and t^2 are the most significant factors associated with the development of the model for average surface roughness. In case of development of model for cutting force, F value of the model is 280.08 and Prob>F is less than 0.001 where t and S_o are the most influencing factors to develop the model. The response surface quadratic equation in terms of actual factors for surface roughness and Main cutting force are stated in eqn. 4 and 5.

Table 5.5 ANOVA for R_a in machining BFRC under compressed air condition

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	1.14	9	0.1267	8.98	0.0010	significant
t	0.0801	1	0.0801	5.68	0.0384	significant
V_c	0.0585	1	0.0585	4.15	0.0691	
S_o	0.0059	1	0.0059	0.4201	0.5315	
$t \times V_c$	0.1785	1	0.1785	12.66	0.0052	significant
$t \times S_o$	0.2015	1	0.2015	14.28	0.0036	significant
$V_c \times S_o$	0.0300	1	0.0300	2.13	0.1756	
t^2	0.2839	1	0.2839	20.13	0.0012	significant
V_c^2	0.0016	1	0.0016	0.1102	0.7468	
S_o^2	0.0107	1	0.0107	0.7606	0.4036	
Residual	0.1411	10	0.0141			
Lack of Fit	0.0923	5	0.0185	1.89	0.2507	not significant
Pure Error	0.0488	5	0.0098			
Corrected Total	1.28	19				

Table 5.6 ANOVA for P_z in machining BFRC under compressed air condition

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	476.24	9	52.92	280.09	< 0.0001	significant
t	430.53	1	430.53	2278.9	< 0.0001	significant
V_c	4.72	1	4.72	25.00	0.0005	significant
S_o	38.90	1	38.90	205.91	< 0.0001	significant
$t \times V_c$	0.0000	1	0.0000	0.000	1.0000	
$t \times S_o$	0.0000	1	0.0000	0.000	1.0000	
$V_c \times S_o$	0.0001	1	0.0001	0.0003	0.9869	
t^2	0.0001	1	0.0001	0.0008	0.9785	
V_c^2	0.0000	1	0.0000	0.0002	0.9889	
S_o^2	0.0001	1	0.0001	0.0007	0.9796	
Residual	1.89	10	0.1889			
Lack of Fit	0.0009	5	0.0002	0.0005	1.0000	not significant
Pure Error	1.89	5	0.3777			
Corrected Total	478.13	19				

$$R_{a\ (BFRC\text{-}Compressed\ air)} = 7.10175 - 7.34283 \times t - 0.00707984 \times V_c - 40.7316 \times S_o + 0.0100476 \times t \times V_c + 21.0763 \times t \times S_o + 0.0492123 \times V_c \times S_o + 3.57029 \times t^2 - 9.84029e\text{-}06 \times V_c^2 + 104.681 \times S_o^2 \quad (4)$$

$$P_{z\ (BFRC\text{-}Compressed\ air)} = -3.052 + 21.8194 \times t + 0.0133344 \times V_c + 76.0562 \times S_o + 4.69512e\text{-}17 \times t \times V_c - 7.24047e\text{-}14 \times t \times S_o + 0.0020808 \times V_c \times S_o + 0.0805769 \times t^2 + 1.54634e\text{-}06 \times V_c^2 + 11.4962 \times S_o^2 \quad (5)$$

Fig 5.3 and Fig 5.4 illustrates 3D response surface plots of average surface roughness under compressed air cooling condition in terms of cutting speed, feed rate and depth of cut

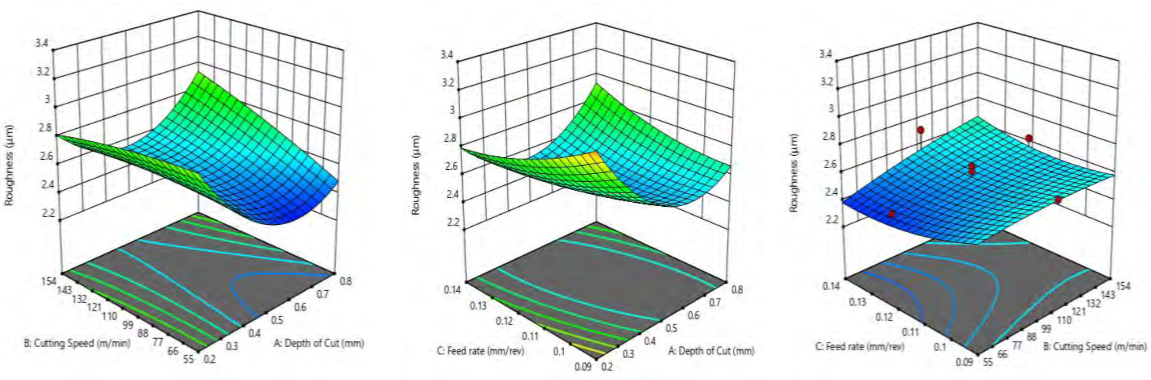


Fig. 5.3 Surface Plots of R_a while machining BFRC under compressed air condition

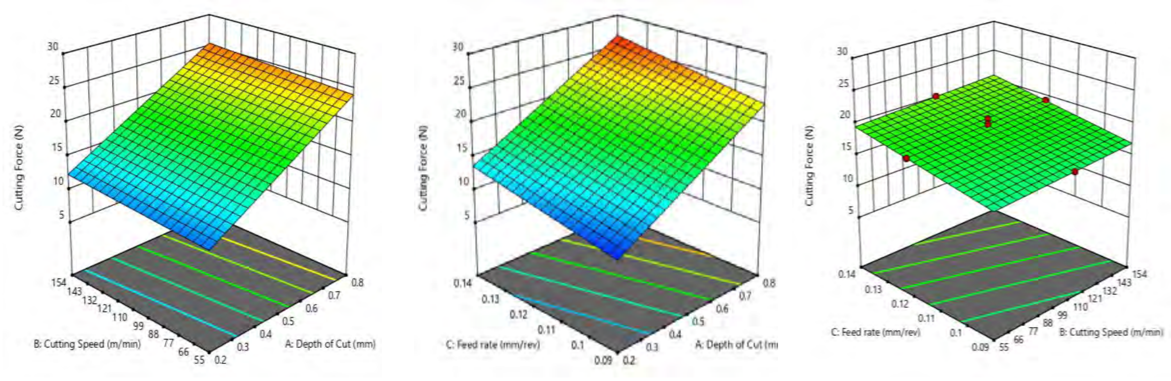


Fig. 5.4 Surface Plots of P_z while machining BFRC under compressed air Condition

5.1.2 Modeling of Surface roughness and Cutting Force of Glass Fiber Reinforced Composite

Table 5.7 shows the statistics summary of the responses or glass fiber reinforced composite for dry condition.

Table 5.7 Design Summary of the responses of GFRC under dry condition

Response	Name	Units	Obs.	Min	Max	Mean	Std. Dev.	Ratio	Model
R1	R_a	μm	20	1.95	2.46	2.21	0.1089	1.26	Quadratic
R2	P_z	N	20	12	31.35	22.05	5.25	2.61	Quadratic

Table 5.8 ANOVA for R_a in machining GFRC under dry condition

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.2241	9	0.0249	176.97	< 0.0001	significant
t	0.1141	1	0.1141	811.10	< 0.0001	
V_c	0.0624	1	0.0624	443.15	< 0.0001	
S_o	0.0462	1	0.0462	328.18	< 0.0001	
$t \times V_c$	0.0000	1	0.0000	0.0780	0.7857	
$t \times S_o$	0.0000	1	0.0000	0.1114	0.7455	
$V_c \times S_o$	9.988E-06	1	9.988E-06	0.0710	0.7953	
t^2	5.181E-06	1	5.181E-06	0.0368	0.8517	
V_c^2	4.677E-08	1	4.677E-08	0.0003	0.9858	
S_o^2	0.0000	1	0.0000	0.1465	0.7099	
Residual	0.0014	10	0.0001			
Lack of Fit	0.0001	5	0.0000	0.0553	0.9968	not significant
Pure Error	0.0013	5	0.0003			
Corrected Total	0.2255	19				

Table 5.9 ANOVA for P_z in machining GFRC under dry condition

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	520.19	9	57.80	181.18	< 0.0001	significant
t	448.00	1	448.00	1404.29	< 0.0001	
V_c	1.52	1	1.52	4.76	0.0541	
S_o	66.68	1	66.68	209.01	< 0.0001	
$t \times V_c$	3.491E-08	1	3.491E-08	1.094E-07	0.9997	
$t \times S_o$	0.0000	1	0.0000	0.0001	0.9907	
$V_c \times S_o$	5.379E-06	1	5.379E-06	0.0000	0.9968	
t^2	0.0212	1	0.0212	0.0663	0.8020	
V_c^2	0.0195	1	0.0195	0.0612	0.8097	
S_o^2	0.0202	1	0.0202	0.0632	0.8065	
Residual	3.19	10	0.3190			
Lack of Fit	0.1755	5	0.0351	0.0582	0.9964	not significant
Pure Error	3.01	5	0.6029			
Corrected Total	523.38	19				

$$R_{a\,(GFRC\text{ - }Dry)} = 1.83602 + 0.358677 \times t - 0.00164948 \times V_c + 3.58747 \times S_o - 7.87861e\text{-}05 \times t \times V_c + 0.185873 \times t \times S_o + 0.000898235 \times V_c \times S_o - 0.0152513 \times t^2 - 5.39815e\text{-}08 \times V_c^2 - 4.5881 \times S_o^2 \quad (6)$$

$$P_{z\,(GFRC\text{ - }Dry)} = -4.4708 + 23.2785 \times t + 0.0150924 \times V_c + 136.104 \times S_o - 4.44283e\text{-}06 \times t \times V_c + 0.317499 \times t \times S_o + 0.000659136 \times V_c \times S_o - 0.974821 \times t^2 - 3.48703e\text{-}05 \times V_c^2 - 143.532 \times S_o^2 \quad (7)$$

Fig 5.5 and 5.6 illustrates 3D response surface plots of average surface roughness and main cutting force for glass fiber reinforced composite under compressed air cooling condition in terms of cutting speed, feed rate and depth of cut.

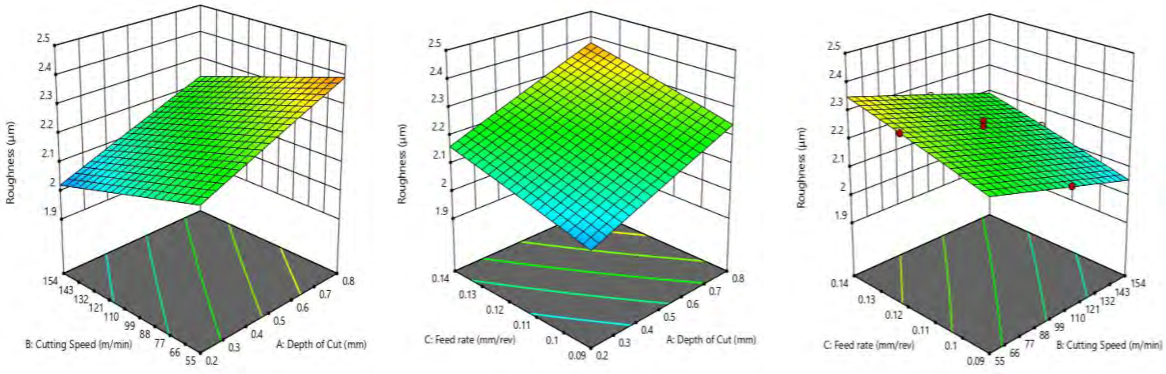


Fig. 5.5 Surface Plots of R_a while machining GFRC under dry condition

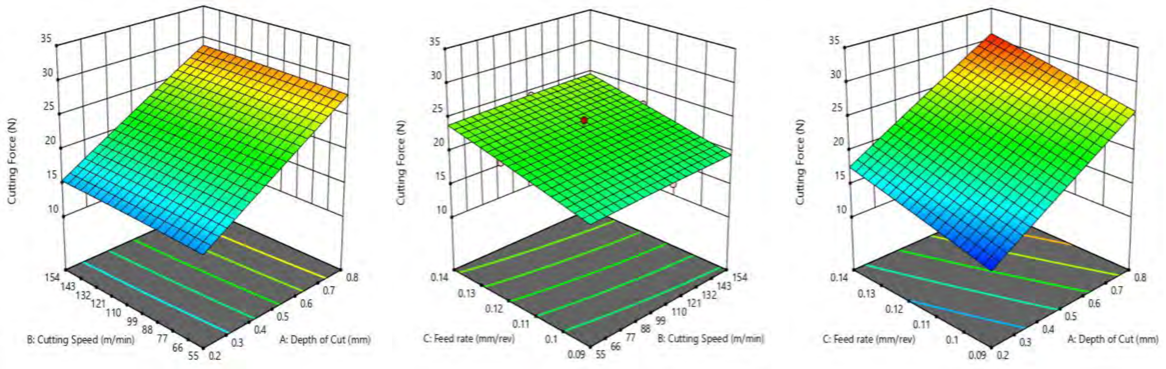


Fig. 5.6 Surface Plots of P_z while machining GFRC under dry condition

Table 5.10 shows the statistics summary of the responses or glass fiber reinforced composite for compressed air cooling condition.

Table 5.10 Design Summary of responses of GFRC in compressed air condition

Response	Name	Units	Obs.	Min	Max	Mean	Std. Dev.	Ratio	Model
R1	R_a	Mm	20	1.86	2.4	2.13	0.1150	1.29	Quadratic
R2	P_z	N	20	7.96	31.04	19.55	6.00	3.90	Quadratic

ANOVA for average surface roughness and main cutting force of glass fiber reinforced composite under compressed air cooling condition are shown in Table 5.11 and 5.12. Measurements implies that statistical significance of the quadratic model as F-value of the model is 205.45 and Prob>F is less than 0.001. For modeling of surface roughness t, V_c and S_o are the most significant factor. In case of development of model for cutting force, F value of the model is 117.68 and Prob>F is less than 0.001 where t and S_o are the most influencing factors to develop the model. Response surface quadratic equation in terms of actual factors for surface roughness and main cutting force are shown in eqn. 8 and 9.

Table 5.11 ANOVA for R_a in machining BFRC under compressed air condition

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.2501	9	0.0278	205.45	< 0.0001	significant
t	0.1207	1	0.1207	892.18	< 0.0001	
V_c	0.0721	1	0.0721	533.05	< 0.0001	
S_o	0.0562	1	0.0562	415.57	< 0.0001	
$t \times V_c$	0.0000	1	0.0000	0.0000	1.0000	
$t \times S_o$	0.0000	1	0.0000	0.0000	1.0000	
$V_c \times S_o$	5.170E-10	1	5.170E-10	3.822E-06	0.9985	
t^2	2.273E-06	1	2.273E-06	0.0168	0.8994	
V_c^2	0.0000	1	0.0000	0.2532	0.6257	
S_o^2	2.248E-06	1	2.248E-06	0.0166	0.9000	
Residual	0.0014	10	0.0001			
Lack of Fit	0.0000	5	3.879E-06	0.0145	0.9999	not significant
Pure Error	0.0013	5	0.0003			
Corrected Total	0.2515	19				

Table 5.12 ANOVA for P_z in machining BFRC under compressed air condition

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	677.60	9	75.29	117.68	< 0.0001	significant
t	593.52	1	593.52	927.68	< 0.0001	
V_c	15.47	1	15.47	24.18	0.0006	
S_o	66.52	1	66.52	103.98	< 0.0001	
$t \times V_c$	9.697E-08	1	9.697E-08	1.516E-07	0.9997	
$t \times S_o$	3.159E-07	1	3.159E-07	4.938E-07	0.9995	
$V_c \times S_o$	0.0000	1	0.0000	0.0000	0.9969	
t^2	0.0471	1	0.0471	0.0737	0.7916	
V_c^2	0.0446	1	0.0446	0.0697	0.7971	
S_o^2	0.0438	1	0.0438	0.0685	0.7989	
Residual	6.40	10	0.6398			
Lack of Fit	0.3870	5	0.0774	0.0644	0.9954	not significant
Pure Error	6.01	5	1.20			
Corrected Total	684.00	19				

$$R_{a\ (GFRC\text{–}Compressed\ air)} = 1.78973 + 0.356565 \times t - 0.00141109 \times V_c + 2.65223 \times S_o - 1.18199e\text{-}19 \times t \times V_c - 8.24423e\text{-}15 \times t \times S_o - 6.46212e\text{-}06 \times V_c \times S_o + 0.0101017 \times t^2 - 1.46092e\text{-}06 \times V_c^2 + 1.51502 \times S_o^2 \quad (8)$$

$$P_{z\ (GFRC\text{-}Compressed\ air)} = 0.786008 + 24.2625 \times t - 0.0360589 \times V_c + 54.6653 \times S_o - 7.40471e\text{-}06 \times t \times V_c - 0.0263904 \times t \times S_o - 0.000912774 \times V_c \times S_o + 1.45465 \times t^2 + 5.27127e\text{-}05 \times V_c^2 + 211.497 \times S_o^2 \quad (9)$$

Fig. 5.7 and 5.8 illustrates 3D surface plots of average surface roughness and main cutting force for glass fiber reinforced composite for compressed for cooling condition.

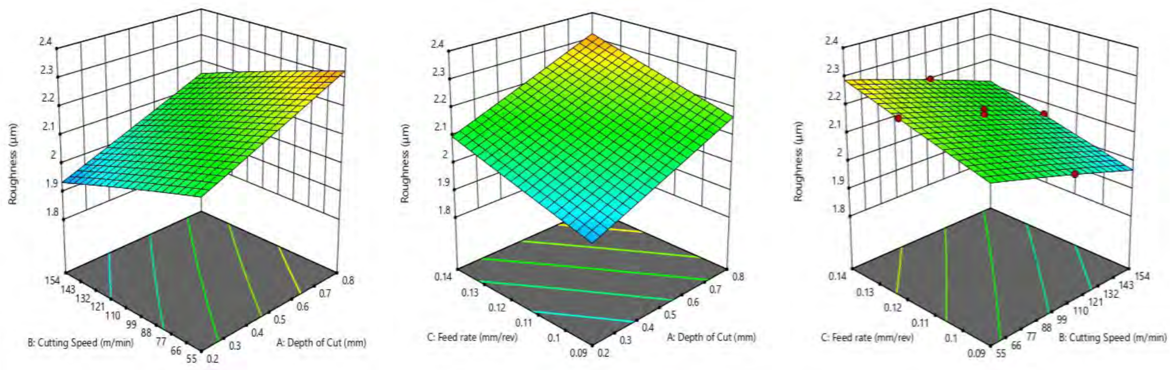


Fig. 5.7 Surface Plots of R_a while machining GFRC under compressed air condition

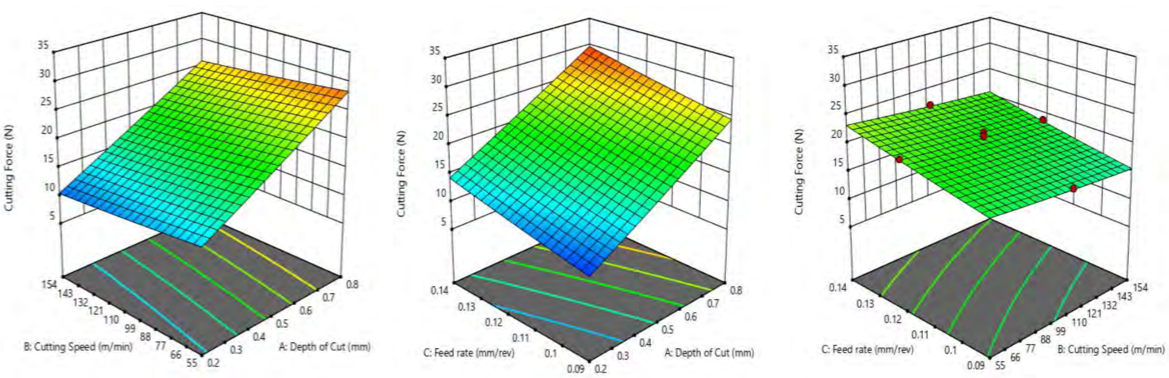


Fig. 5.8 Surface Plots of P_z while machining GFRC under compressed air condition

5.1.3 Desirability Function Analysis for Banana fiber reinforced composite

Numerical optimization by desirability function is conducted by employing response surface equations of the machining responses. According to Myers and Montogomery [**Myers et al. 2016**], Desirability function is an objective function (D), the value (d_i) of which ranges from 0 (least) to 1 (most). The function has the capability to search for a point in the specified design space within the constrained levels of factor settings and considering weight and importance which not only suffice all the goal addressed as shown in table 5.13 and Table 5.14 but it also search for the highest desirable value possible, $d_{i=}$ 1. During this optimization process, aim is to achieve optimum levels of factor settings, which yield the lowest quantity of average surface roughness and main cutting force. Eqn. 10 is the desirability function where n is the number of responses. A weight value can be assigned to a goal to adjust the shape of its particular desirability function. Here identical weights value are assigned to all the factors and responses. Importance of 3 out of 5 are given to the factors.

$$D = (d_1\ x\ d_2\ x \ldots x\ d_n)^{\frac{1}{n}} = \left(\prod_{i=1}^{n} d_i\right)^{\frac{1}{n}}$$

$$D = (d_1^{r_1}\ x\ d_2^{r_2}\ x \ldots x\ d_n^{r_n})^{\frac{1}{n}} = \left(\prod_{i=1}^{n} d_i^{\,r_i}\right)^{\frac{1}{\Sigma r_i}}$$

For goal as a target, the desirability can be defined by the following formulas:

$d_i = 0$, $\quad$ $Response_i \leq Low_i$

$d_i = \left[\frac{Response_i - Low_i}{Target_i - Low_i}\right]^{wt_i}$, $\quad$ $Low_i < Response_i < Target_i$

$d_i = 1$, $\quad$ $Response_i = Target_i$

$d_i = \left[\frac{High_i - Response_i}{High_i - Target_i}\right]^{wt_i}$, $\quad$ $Target_i < Response_i < High_i$

$d_i = 0$, $\quad$ $Response_i \geq Low_i$

For goal within range (a constraint), desirability will be defined by the following formuals:

$d_i = 0$, $\quad$ $Response_i \leq Low_i$

$d_i = 1$, $\quad$ $Low_i < Response_i < High_i$

$d_i = 0$, $\quad$ $Response_i \geq High_i$

Table 5.13 Constraints of multi-objective optimization for BFRC under dry condition

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
Depth of Cut	is in range	0.2	0.8	1	1	3
Cutting Speed	minimize	55	154	1	1	3
Feed rate	is in range	0.08	0.14	1	1	3
Roughness	is target = 2.57	2.57	3.35	1	1	3
Cutting Force	is target = 10.77	10.77	30.39	1	1	3

The optimum solutions for BFRC under dry condition are stated in Table 5.14. According to the best result (desirability = 0.926), the optimum cutting parameters which yielded the R_a =2.570 µm, P_z = 14.824 N are follows: 0.373 mm of t, 55 m/min of V_c and 0.08 mm/rev For a clear Evaluation, desirability value of each individual factor and responses associated are shown in Fig. 5.9

Table 5.14 Desirability optimizations solutions for BFRC under dry condition

No.	Depth of Cut	Cutting Speed	Feed rate	Roughness	Cutting Force	Desirability	
1	**0.373**	**55.000**	**0.080**	**2.570**	**14.824**	**0.926**	**Selected**
2	0.369	55.000	0.080	2.575	14.742	0.925	
3	0.373	55.000	0.080	2.570	14.844	0.925	
4	0.373	55.006	0.081	2.570	14.883	0.925	
5	0.373	55.376	0.080	2.570	14.848	0.924	
6	0.359	55.000	0.080	2.590	14.503	0.924	

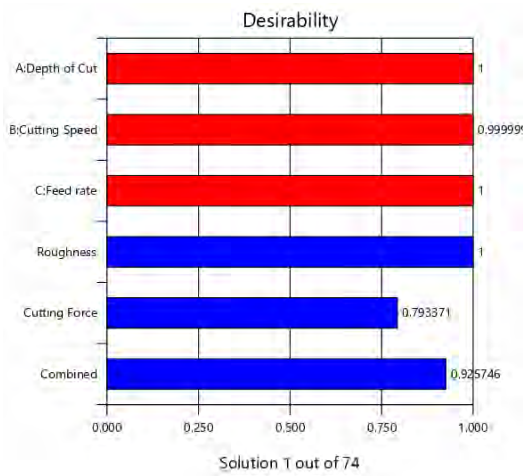


Fig. 5.9 Desirability analysis of BFRC under dry condition

Similarly, desirability analysis under compressed air condition was performed by taking into consideration all the constraints as shown in Table 5.15

Table 5.15 Constraints of multi-objective optimization for BFRC under CA condition

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
Depth of Cut	is in range	0.2	0.8	1	1	3
Cutting Speed	minimize	55	154	1	1	3
Feed rate	is in range	0.08	0.14	1	1	3
Roughness	is target = 2.33	2.33	3.32	1	1	3
Cutting Force	is target = 9	9	27.46	1	1	3

The optimum solutions for BFRC under compressed air condition are stated in Table 5.16. to the best result (desirability = 0.810), the optimum cutting parameters which yielded the R_a =2.511 µm, P_z = 15.457 N are follows: 0.403 mm of t, 55 m/min of V_c and 0.116 mm/rev. For a clear Evaluation, desirability value of each individual factor and responses associated are shown in Fig. 5.10.

Table 5.16 Desirability optimizations solutions for BFRC under CA condition

No.	Depth of Cut	Cutting Speed	Feed rate	Roughness	Cutting Force	Desirability	
1	**0.403**	**55.000**	**0.116**	**2.511**	**15.457**	**0.810**	**Selected**
2	0.398	55.000	0.120	2.496	15.692	0.809	
3	0.422	55.000	0.110	2.513	15.460	0.809	
4	0.384	55.000	0.121	2.512	15.466	0.809	
5	0.414	55.000	0.110	2.525	15.277	0.809	
6	0.429	55.000	0.110	2.503	15.613	0.809	

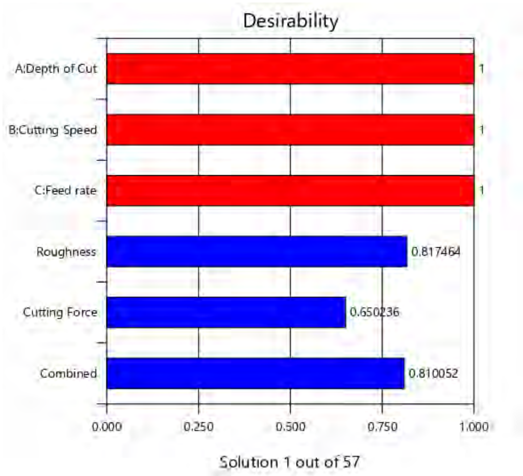


Fig. 5.10 Desirability analysis of BFRC under compressed air condition

5.1.4 Desirability Function Analysis of Glass Fiber Reinforced Composite

Composite desirability analysis has been under dry and compressed air condition for glass fiber reinforced epoxy composite as shown in Table 5.17 and 5.19 by taking all the relevant constraints into consideration.

Table 5.17 Constraints of multi-objective optimization for GFRC under dry condition

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
Depth of Cut	is in range	0.2	0.8	1	1	3
Cutting Speed	minimize	55	154	1	1	3
Feed rate	is in range	0.08	0.14	1	1	3

Roughness	is target = 1.95	1.95	2.46	1	1	3
Cutting Force	is target = 12	12	31.35	1	1	3

The optimum solutions for GFRC under dry condition are stated in Table 5.18. where the optimum cutting parameters which yielded the R_a =2.109 µm, P_z = 12 N are follows: 0.201 mm of t, 55 m/min of V_c and 0.08 mm/rev. For a clear Evaluation, desirability value of each individual factor and responses associated are shown in Fig. 5.11.

Table 5.18 Desirability optimizations solutions for GFRC under dry condition

No.	Depth of Cut	Cutting Speed	Feed rate	Roughness	Cutting Force	Desirability	
1	**0.201**	**55.000**	**0.080**	**2.109**	**12.000**	**0.883**	**Selected**
2	0.201	55.001	0.080	2.110	12.000	0.882	
3	0.201	55.426	0.080	2.109	12.000	0.882	
4	0.204	55.000	0.080	2.110	12.058	0.881	
5	0.201	56.635	0.080	2.107	12.000	0.880	
6	0.200	55.130	0.081	2.111	12.057	0.880	

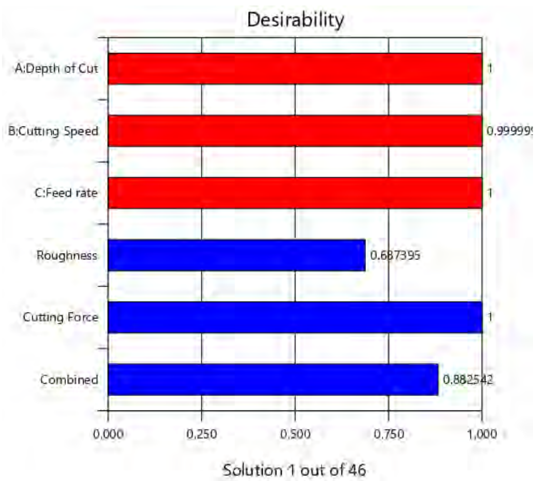


Fig. 5.11 Desirability analysis of GFRC under dry condition

Table 5.19 Constraints of multi-objective optimization for GFRC under CA condition

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
Depth of Cut	is in range	0.2	0.8	1	1	3
Cutting Speed	minimize	55	154	1	1	3
Feed rate	is in range	0.08	0.14	1	1	3
Roughness	is target = 1.86	1.86	2.4	1	1	3
Cutting Force	is target = 7.96	7.96	31.04	1	1	3

The optimum solutions for GFRC under compressed air condition are stated in Table 5.20.

For desirability = 0.848, the optimum cutting parameters which yielded the R_a =2.030 µm, P_z = 10.501 N are follows: 0.2 mm of t, 55 m/min of V_c and 0.08 mm/rev. Desirability value of each individual factor and responses associated are shown in Fig. 5.12.

Table 5.20 Desirability optimizations solutions for GFRC under CA condition

No.	Depth of Cut	Cutting Speed	Feed rate	Roughness	Cutting Force	Desirability	
1	**0.200**	**55.000**	**0.080**	**2.030**	**10.501**	**0.848**	**Selected**
2	0.200	55.438	0.080	2.030	10.488	0.847	
3	0.200	55.865	0.080	2.029	10.475	0.847	
4	0.202	55.114	0.080	2.031	10.558	0.846	
5	0.206	55.028	0.080	2.032	10.649	0.844	
6	0.200	68.319	0.080	2.009	10.106	0.828	

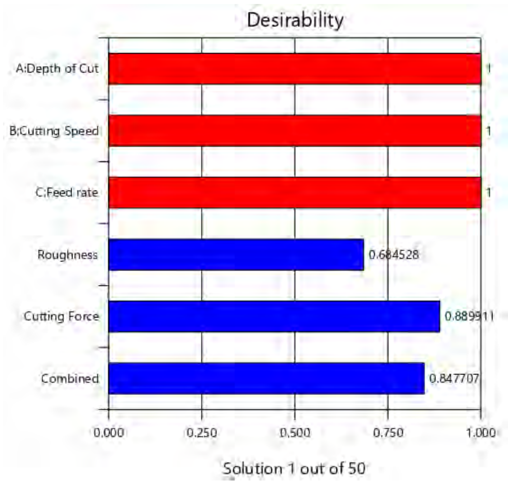


Fig. 5.12 Desirability analysis of GFRC under compressed air condition

5.2 Modeling by Artificial Neural Network

An artificial neural network (ANN) is a computational model in view of the structure and elements of organic neural systems. As the "neural" some portion of their name recommends, they are mind-motivated frameworks, which are proposed to imitate the way that we people learn. Neural systems comprise of input and output layers, and in addition (much of the time) a hidden layer comprising of units that change the input to something that the output layer can utilize. They are great tools for discovering designs which are very intricate or numerous for a human software engineer to concentrate and instruct the machine to perceive. Data that courses through the system influence the structure of the ANN in light of the fact that a neural system changes - or learns, it could be said - in view of that input and output. ANNs are viewed as nonlinear statistical information demonstrating tools where the complex relationships amongst inputs and outputs are displayed or designs are found.

ANNs have three layers that are interconnected. The primary layer comprises of input neurons. Those neurons send data on to the second layer, which in turn sends the output neurons to the third layer. Learning ability and use of different learning algorithms are the key features of artificial neural network. Best learning algorithm and optimum number of neurons need to be determined to get a minimal deviation between experimental values and output values. Gradient descent backpropagation (GD), quasi-Newton backpropagation (BFG), Levenberg-Marquardt backpropagation (LM), scaled conjugate gradient backpropagation (SCG), Resilient backpropagation (RP), Conjugate gradient backpropagation with Polak-Ribiére updates (CGP), Bayesian regulation backpropagation (BR) are different types of learning algorithms used in network training process.

There are two types of neural networks: the feed-forward types and the recurrent ones. Feed-forward neural networks allow the signals to travel in only one direction which is from input to output i.e. the output signal of a neuron is the input of the neurons of the following layer and never the opposite. The inputs of the first layer are considered the input signals of the whole network and the output of the network is the output signals of last layer‘s neurons. On the contrary, recurrent networks include feedback loops allowing signals to travel forward and/or backward. Feed-forward neural networks are characterized by simple structure and easy mathematical description. Therefore, they have been selected for the modeling of surface roughness in the present thesis.

Fig. 5.13 presents the schematic diagram of the developed neural network which depicts a feed forward neural network containing three input neurons in input layer, 1 hidden layer containing 6 neurons and an output layer containing two output neuron. In the present research work, six neural networks have been designed, trained and tested in order to determine the optimal ANN architecture. Among different combinations of R_a under dry and compressed air cooling condition; 16 combinations have been used in the training process whereas 4 combinations have been used in the testing process. Surface roughness resulted from each of the depth of cut among 0.2 mm, 0.5 mm and 0.8 mm; three cutting speeds 55 m/min., 110 m/min., 154 m/min. and three feeds 0.10 mm/rev., 0.12 mm/rev., and 0.14 mm /rev. were used for the training purpose of the neural network. For modeling purpose, values of surface roughness and cutting force were taken only from the machining of GFRC and BFRC under dry and compressed air cooling condition.

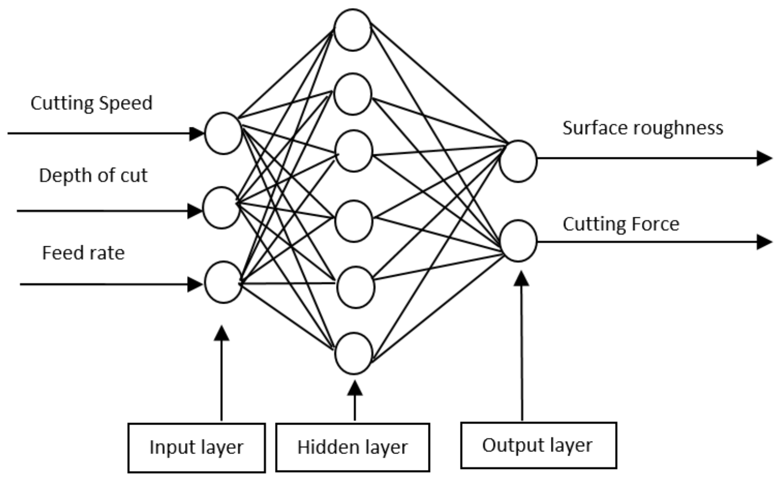


Fig. 5.13 ANN architecture for the developed model (3-n-2)

While analyzing data for banana fiber reinforced composite, optimal network is found at 3-10-2 for dry cutting condition whereas, 3-12-2 is the optimal network structure for compressed air cooling condition. Table 5.21 presents the summary of the optimal network architecture.

Table 5.21 Summary of the ANN model for 3-10-2 and 3-12-2 ANN architecture for surface roughness prediction of Banana fiber reinforced polyester composite

Type of neural network	: Multi layer feed-forward
Input neurons	: Cutting speed, V_c (m/min.) : Feed rate, S_o (mm/rev.) : Depth of cut, t (mm)
Output neuron	: Average surface roughness (Ra), Cutting Force (P_z)
Number of Hidden layer	: 1
Hidden neurons	: 10 for dry condition; 12 for compressed air condition
Training Function	: TRAINLM
Adaptive Learning Function	: LEARNGD
Transfer function	: Tangent sigmoid (Hidden layer) : Linear transfer function (Output layer)
Sample pattern vector	: 16 (for training) and 4 (for testing)

Among 20 dataset, 16 dataset are taken for training purpose and 4 dataset are taken for testing for all the conditions. To obtain the output closest to the experimental data for both GFRC and BFRC, the number of neurons in hidden layers is taken as 10 for dry condition and 12 for compressed air condition. So, the networks are 3-10-2 and 3-12-2 for dry condition and compressed air condition respectively. Proposed ANN structure depicts that it has 3 neurons (depth of cut, cutting speed and feed rate) in the input layer, ten (for dry condition) and 12 (for compressed air condition) neurons in the hidden layer and two neurons (surface roughness and cutting force) in output layer. Fig. 5.14 presents the regression plots for various phases. According to ANN, the value of Coefficient of correlation (R^2) must be near to 1. In this experiment, the R^2 values of training, validation, testing and all cases ranges from 0.98-0.99 which are close to the 1 that indicates the best predicted output values based on experimental inputs and outputs.

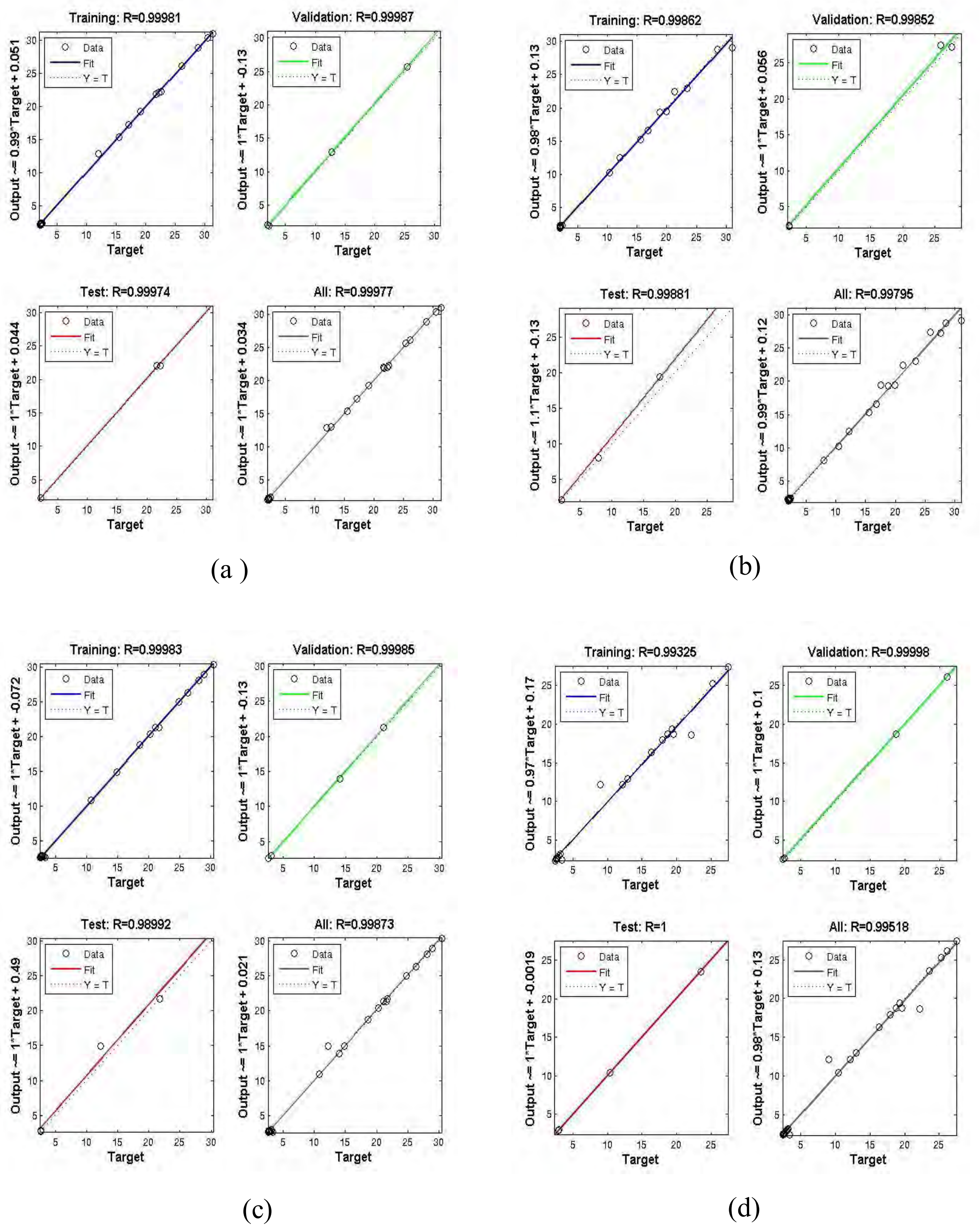


Fig. 5.14 Linear Regression Plot for surface roughness and cutting force while machining (a) GFRC in Dry Condition (b) GFRC in Compressed Air Condition (c) BFRC in Dry Condition (d) BFRC in Compressed Air Condition

Chapter-6

Discussion on Results

6.1 Surface Roughness

In machining operation, the quality of surface finish is an important requirement for many turned work pieces. Surface quality is one of the most specified customer requirements where major indication of surface quality on machined parts is surface roughness. Thus, the choice of optimum cutting parameters is very important to control the required surface quality. Surface roughness is a vital measure as it may influence frictional resistance, fatigue strength or creep life of machined components. As far as turned components are concerned, low surface roughness is important as it can reduce or even completely eliminate the need of further machining. Many researchers have found that surface roughness has bearing on heat transmission, ability to hold lubricant, surface friction, wearing etc. Despite the fact that surface roughness plays a very important role in the utility and life of a machined component due to its dependence on several process parameters and numerous uncontrollable factors machining process has no complete control over surface finish obtained. So, the venture of controlling process parameters so as to produce best surface finish is an on-going process varying from various material to tool combinations and the machining conditions.

As per experimental data analysis, variation of surface roughness in different cutting conditions is evident and for almost every cutting condition, reasonable surface roughness value is found. It is obvious that the trend of surface roughness is mainly increasing with increased feed rate indifferent of the cutting speed. When the cutting speed is in concern, surface roughness is mainly decreased with increased cutting speed regardless the values of feed rate. Significant amount of reduction in surface roughness is also found while machining the composites under compressed air cooling condition.

Table 6.1 Percentage of reduction in R_a for BFRC under dry and compressed air condition

Process Parameters			Environment		Percentage of reduction
t (mm)	V_c (m/min)	S_o (mm/rev)	Dry R_a (μm)	Compressed air R_a (μm)	(%)
0.5	110	0.08	2.70	2.60	3.70
0.8	154	0.14	3.35	3.10	7.46
0.8	55	0.08	2.62	2.42	7.63
0.2	55	0.08	2.83	3.32	-17.31
0.5	55	0.12	2.67	2.48	7.12
0.8	55	0.14	2.62	2.61	0.38
0.2	154	0.08	2.69	2.98	-10.78
0.5	110	0.12	2.62	2.55	2.67
0.8	154	0.09	2.87	2.84	1.05
0.5	110	0.12	2.60	2.48	4.62
0.5	110	0.12	2.65	2.59	2.26
0.2	55	0.14	2.77	2.72	1.81
0.5	154	0.12	2.68	2.63	1.87
0.2	110	0.12	3.10	2.89	6.77
0.8	110	0.12	3.12	2.93	6.09
0.5	110	0.12	2.57	2.33	9.34
0.5	110	0.12	2.61	2.39	8.43
0.2	154	0.14	2.88	2.79	3.13
0.5	110	0.14	2.76	2.71	1.81
0.5	110	0.12	2.61	2.42	7.28

The effect of dry condition and compressed air condition on surface roughness is shown in table 6.1. The surface roughness is reduced up to 9.34% while machining BFRC in compressed air condition.

From table 6.2, highest reduction of surface roughness is found at run 20 and the value of surface roughness is reduced up to 4.01% while machining GFRC in compressed air condition.

Table 6.2 Percentage of reduction in R_a of GFRC under dry and compressed air condition

Process Parameters			Environment		Percentage of reduction
t (mm)	V_c (m/min)	S_o (mm/rev)	Dry	Compressed air	(%)
			R_a (µm)	R_a (µm)	
0.5	110	0.08	2.13	2.05	3.76
0.8	154	0.14	2.30	2.23	3.04
0.8	55	0.08	2.32	2.25	3.02
0.2	55	0.08	2.11	2.03	3.79
0.5	55	0.12	2.30	2.23	3.04
0.8	55	0.14	2.46	2.40	2.44
0.2	154	0.08	1.95	1.86	4.62
0.5	110	0.12	2.21	2.14	3.17
0.8	154	0.08	2.16	2.08	3.70
0.5	110	0.12	2.21	2.14	3.17
0.5	110	0.12	2.19	2.11	3.65
0.2	55	0.14	2.24	2.18	2.68
0.5	154	0.12	2.14	2.06	3.74
0.2	110	0.12	2.10	2.03	3.33
0.8	110	0.12	2.32	2.25	3.02
0.5	110	0.12	2.21	2.14	3.17
0.5	110	0.12	2.24	2.16	3.57
0.2	154	0.14	2.09	2.01	3.83
0.5	110	0.14	2.26	2.20	2.65
0.5	110	0.12	2.22	2.13	4.05

6.2 Cutting Force

Cutting force is tied to the relative movement between tool and work piece. As relates to the resistance to motion, it cannot be regarded as a constant variable in time. It is important in machining because they provide distinctive signature of the mechanics of machining. It plays a primary role in determining the energy consumed and machining power requirements of process, tool and workpiece deflections. In hard turning, because of the high hardness of the workpiece, it results in higher cutting forces than usual and this reduces the performance of the cutting tool. Material properties that affect cutting forces include hardness, tensile strength, impact, and toughness. Each of the properties generate different levels of resistance and require more or less force.

Materials such as most heat-resistant alloys need lighter depths of cuts because the forces generated in those types of materials are far greater than in other materials. In addition, they have tendencies to work-harden easily with heat being generated from higher cutting forces. Forty-five-degree cutters or positive cutting tool geometries are usually preferred to minimize these forces. The type of holder also plays a role in how the tool reacts with specific cutting conditions. Materials with higher tensile strength require more power and thus they generate high cutting force between the tool and the workpiece. Thus, knowledge of the cutting forces is important as they have a direct influence on the generation of heat, and thus on tool wear, quality of machined surface and accuracy of work piece.

Table 6.3 Percentage of reduction in P_z of BFRC under dry and compressed air condition

Process Parameters			Environment		Percentage of reduction
t (mm)	V_c (m/min)	S_o (mm/rev)	Dry	Compressed air	(%)
			P_z (N)	P_z (N)	
0.5	110	0.08	18.61	16.33	12.25
0.8	154	0.14	30.39	27.46	9.64
0.8	55	0.08	24.81	22.14	10.76
0.2	55	0.08	10.77	9.00	16.43
0.5	55	0.12	20.26	17.93	11.50
0.8	55	0.14	28.92	26.08	9.82
0.2	154	0.08	12.24	10.37	15.28
0.5	110	0.12	21.07	18.70	11.25
0.8	154	0.08	26.27	23.51	10.51
0.5	110	0.12	21.07	18.70	11.25
0.5	110	0.12	21.07	19.60	6.98
0.2	55	0.14	14.88	12.94	13.04
0.5	154	0.12	21.72	19.31	11.10
0.2	110	0.12	14.05	12.13	13.67
0.8	110	0.12	28.09	25.27	10.04
0.5	110	0.12	21.60	18.70	13.43
0.5	110	0.12	21.07	17.66	16.18
0.2	154	0.14	16.35	14.32	12.42
0.5	110	0.14	22.72	20.28	10.74
0.5	110	0.12	21.07	18.70	11.25

According to the data found from experimental analysis for variation of main cutting force with feed rate, it is evident that for almost every cutting condition; reasonable values of cutting force are found. Trend mainly shows increased cutting force with increased feed rate regardless of the machining environment. Again, for a particular feed, cutting force is mainly decreased with increased cutting speed. The trend of cutting force was increasing with increased feed rate regardless of the cutting speed. One distinguished thing was that for increased depth of cut the value of the cutting force increased drastically. The reason is with increased depth of cut, the cutting tool penetrates more and removes more amount of material resulting increased cutting force.

Table 6.3 represents how cutting force differs in dry and compressed air condition and in which condition gives the best outcome. Looking at the two conditions, the cutting force is reduced up to 16.43% while machining BFRC in compressed air condition.

Table 6.4 Percentage of reduction in P_z of GFRC under dry and compressed air condition

Process Parameters			Environment		Percentage of reduction
t (mm)	V_c (m/min)	S_o (mm/rev)	Dry	Compressed air	(%)
			P_z (N)	P_z (N)	
0.5	110	0.08	19.13	16.78	12.28
0.8	154	0.14	31.35	28.55	8.93
0.8	55	0.08	25.4	25.88	-1.88
0.2	55	0.08	12	10.45	12.91
0.5	55	0.12	21.8	21.26	2.47
0.8	55	0.14	30.57	31.04	-1.53
0.2	154	0.08	12.78	7.96	37.71
0.5	110	0.12	22.23	19.88	10.57
0.8	154	0.08	26.18	23.39	10.65
0.5	110	0.12	22.23	19.88	10.57
0.5	110	0.12	21.6	17.6	18.51
0.2	55	0.14	17.16	15.61	9.03
0.5	154	0.12	22.58	18.77	16.87
0.2	110	0.12	15.53	12.17	21.63
0.8	110	0.12	28.93	27.59	4.63
0.5	110	0.12	22.23	19.88	10.57
0.5	110	0.12	23.5	20.6	12.34
0.2	154	0.14	17.94	13.12	26.86
0.5	110	0.14	24.3	21.94	9.711
0.5	110	0.12	23.5	18.6	20.85

Table 6.4 illustrates how cutting force varies in dry and compressed air condition and in which condition gives the best result. Comparing both conditions, it is seen that at the same cutting parameter, the cutting force in compressed air condition is lower than the cutting force in dry condition. The cutting force is reduced upto 37.71% while machining GFRC in compressed air condition.

6.3 Prediction of cutting force and surface roughness using ANN

Table 6.5 ANN predicted values for outputs while machining Banana Fiber Reinforced Composite

Process Parameters			Environment			
t (mm)	V_c (m/min)	S_o (mm/rev)	Dry Condition		Compressed air condition	
			R_a (μm)	P_z (N)	R_a (μm)	P_z (N)
0.5	110	0.08	2.717	18.7534	2.6001	16.32
0.8	154	0.14	2.5887	30.351	3.0995	27.45
0.8	55	0.08	2.6467	24.95	2.3468	18.60
0.2	55	0.08	2.7939	10.8602	2.3766	12.16
0.5	55	0.12	2.6986	20.3645	2.48	17.93
0.8	55	0.14	2.5892	28.8666	2.6091	26.09
0.2	154	0.08	2.81	14.9289	2.98	10.37
0.5	110	0.12	2.6428	21.289	2.5149	18.72
0.8	154	0.08	2.8907	26.3038	2.8399	23.51
0.5	110	0.12	2.6428	21.289	2.5149	18.72
0.5	110	0.12	2.6428	21.289	2.5149	18.72
0.2	55	0.14	2.8225	14.9105	2.72	12.94
0.5	154	0.12	2.6702	21.6461	2.6291	19.34
0.2	110	0.12	2.9376	13.8862	2.89	12.12
0.8	110	0.12	2.7627	28.0954	2.929	25.29
0.5	110	0.12	2.6428	21.289	2.5149	18.72
0.5	110	0.12	2.6428	21.289	2.5149	18.72
0.2	154	0.14	2.656	24.3191	2.7669	24.96
0.5	110	0.14	2.6112	28.3377	2.7781	26.41
0.5	110	0.12	2.6428	21.289	2.5149	18.72

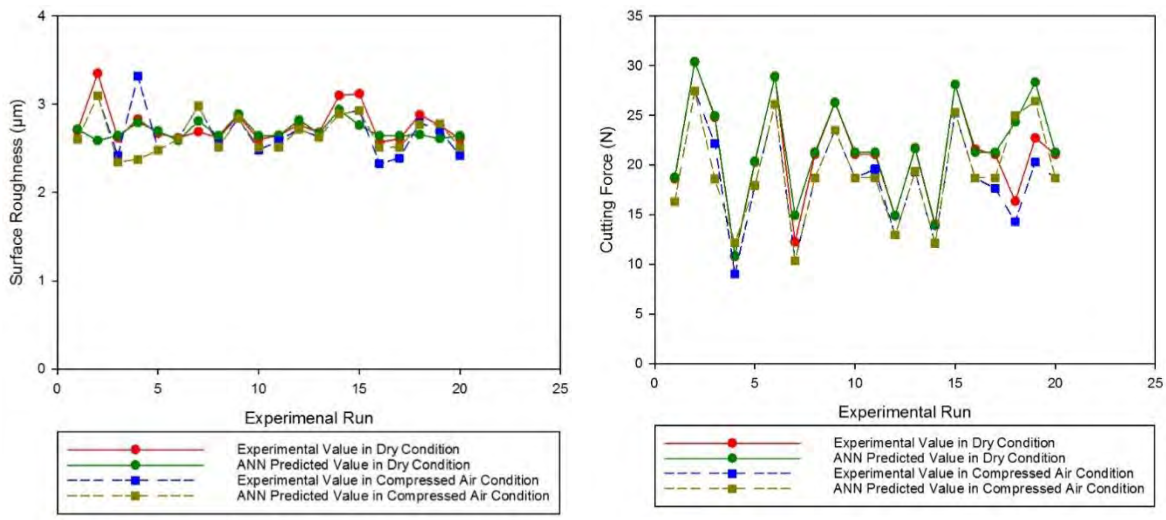
From the table 6.5 the impact of compressed air condition is clearly seen over dry condition. ANN gives similar types of result for BFRC like GFRC. Here, the values of surface roughness and cutting force in compressed air condition are less than the values of dry condition. So it can be concluded saying that machining of GFRC and BFRC ought to be done under compressed air condition rather than dry condition as compressed air gives lower surface roughness and cutting force.

Table-6.6 ANN predicted values for outputs while machining Glass Fiber Reinforced Composite

Process Parameters			Environment			
t (mm)	V_c (m/min)	S_o (mm/rev)	Dry Condition		Compressed air condition	
			R_a (µm)	P_z (N)	R_a (µm)	P_z (N)
0.5	110	0.08	2.1078	19.2471	2.0646	16.75
0.8	154	0.14	2.2931	31.0129	2.223	28.56
0.8	55	0.08	1.9995	25.7149	2.2471	25.85
0.2	55	0.08	2.091	12.8561	2.1944	10.45
0.5	55	0.12	2.2889	21.9384	2.244	21.23
0.8	55	0.14	2.3588	30.4188	2.3909	31.02
0.2	154	0.08	2.023	13.0146	1.8731	7.97
0.5	110	0.12	2.2513	22.0882	2.1394	19.86
0.8	154	0.08	2.1363	26.1884	2.0313	23.38
0.5	110	0.12	2.2513	22.0882	2.1394	19.86
0.5	110	0.12	2.2513	22.0882	2.1394	19.86
0.2	55	0.14	2.2084	17.2354	2.3247	22.35
0.5	154	0.12	2.1314	22.2174	1.9822	16.50
0.2	110	0.12	2.1693	15.3399	1.9992	8.21
0.8	110	0.12	2.3241	28.8621	2.255	27.57
0.5	110	0.12	2.2513	22.0882	2.1394	19.86
0.5	110	0.12	2.2513	22.0882	2.1394	19.86
0.2	154	0.14	2.286	27.9128	2.1633	28.70
0.5	110	0.14	2.2321	29.7586	2.2758	30.41
0.5	110	0.12	2.2513	22.0882	2.1394	19.86

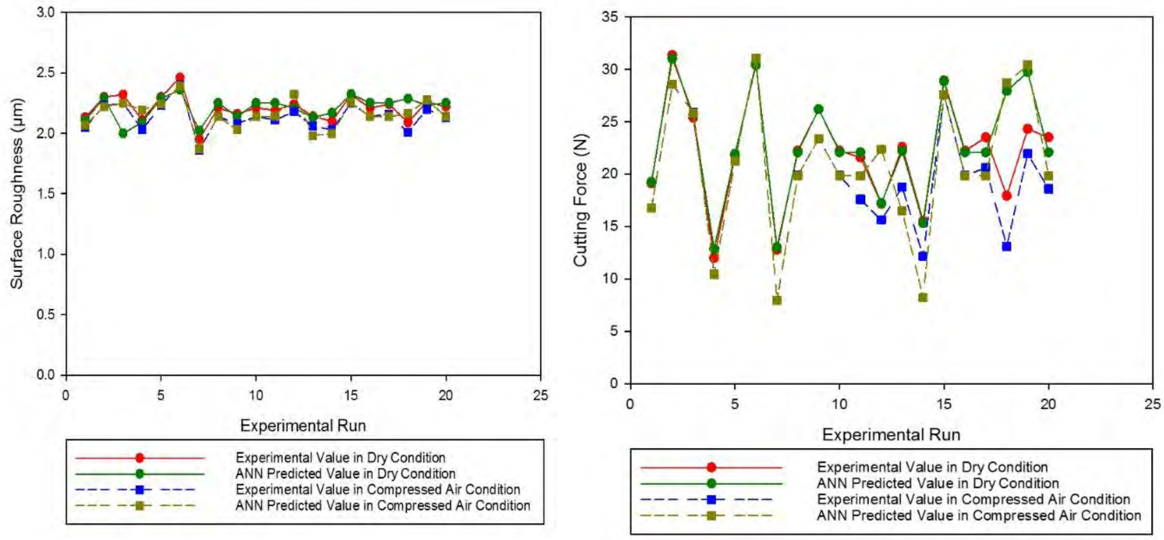
From the ANN anticipated data of GFRC under both dry and compressed air condition, it is clearly seen that the estimations of surface roughness and cutting force are decreased in compressed air condition. Along these lines, in view of ANN predicted values it is desirable to use compressed air condition instead of dry condition in machining GFRC.

Fig. 6.1 also implies the comparison of experimental values and ANN predicted values in terms of surface roughness and cutting force while machining BFRC under both dry and compressed air condition. These two graphical portrayals indicate how ANN predicted values vary from experimental values. Nevertheless, from the figures it is observed that ANN effectively predicted the output values of the experiment as the values are close enough to the experimental ones. Similarly, Fig. 6.2 infers the comparison of experimental values and ANN predicted values in terms of surface roughness and cutting force while machining GFRC under both dry and compressed air condition. The above figures clearly show how ANN precisely predicts the values of surface roughness and cutting force. Experimental values and ANN predicted values almost near to one another in both dry and compressed air condition.



(a) (b)

Fig. 6.1 Comparison of measured and predicted R_a and P_z with in machining glass fiber reinforced composite under (a) dry and (b) compressed air conditions.



(a) (b)

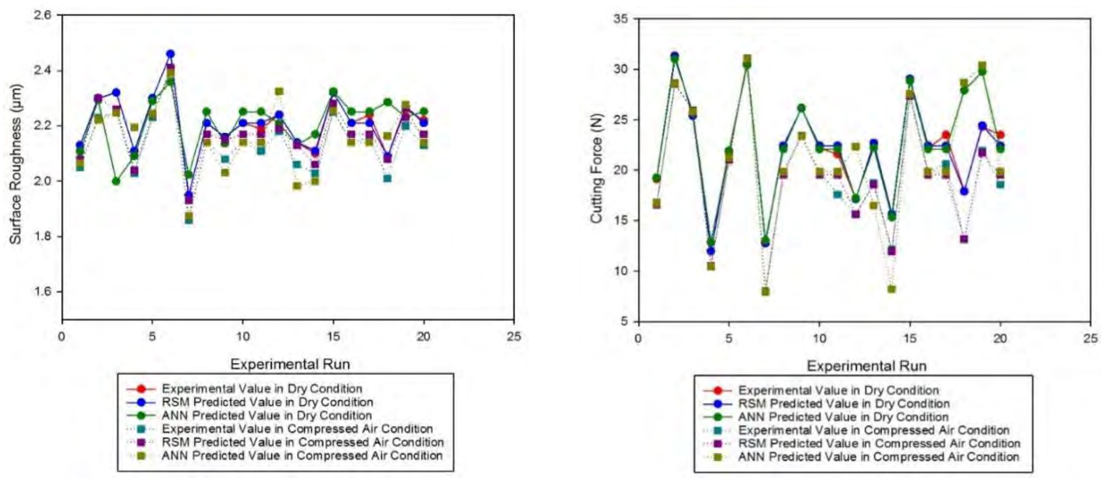
Fig. 6.2 Comparison of measured and predicted R_a and P_z with in machining banana fiber reinforced composite under (a) dry and (b) compressed air conditions.

6.4 Comparison of RSM and ANN predicted data

The following graphical representations (Fig. 6.3 and 6.4) demonstrate the variation among experimental, RSM predicted and ANN predicted surface roughness and cutting force for both GFRC and BFRC under dry and compressed air condition.

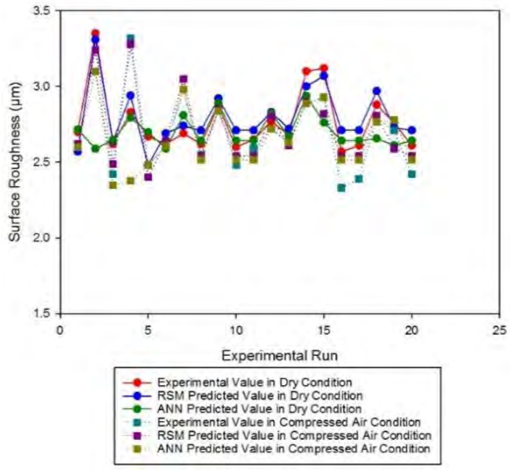
From Fig. 6.3, it is clearly noticed that for Glass Fiber Reinforced Composite (GFRC), RSM predicted values (surface roughness and cutting force) are closer to the experimental values than ANN predicted values in dry condition. Therefore, RSM has better prediction capability than ANN for GFRC in dry condition. However, in compressed air condition, both RSM and ANN predicted values are in equidistance from the experimental ones. Hence, it can be concluded that for predicting output values of GFRC under compressed air condition both RSM and ANN may be preferred.

Fig. 6.4, which is for Banana Fiber Reinforced Composite (BFRC), shows similar types of results like GFRC. Here also, in dry condition, RSM gave the accurate prediction comparing to ANN and in compressed air condition both RSM and ANN have the ability to predict surface roughness and cutting force effectively.

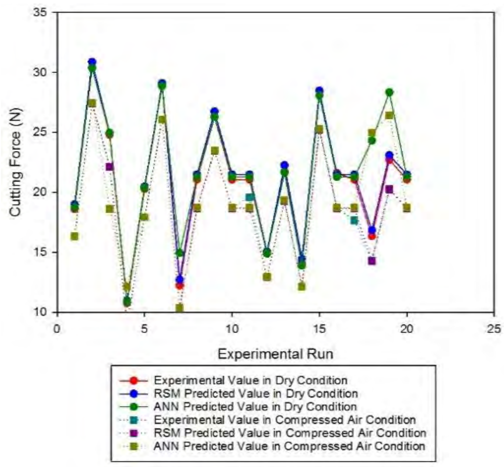


(a) (b)

Fig. 6.3 Comparison of measured and predicted R_a and P_z in machining glass fiber reinforced composite under dry and compressed air conditions



(a)



(b)

Fig. 6.4 Comparison of measured and predicted R_a and P_z in machining banana fiber reinforced composite under dry and compressed air conditions

Chapter-7

Conclusions and Recommendation

From the experimental investigation, machining of banana fiber reinforced epoxy composite and modeling of surface roughness and cutting force, following conclusions can be listed as follows:

Conclusions

- Alkaline treated banana fiber reinforced epoxy composite has been developed to analysis the properties of the fabricated fiber to compare it with that of glass fiber and banana-glass hybrid fiber.
- Tensile strength, impact strength and flexural strength of BFRP composite is on the lower side compared to that of GFRP composite, However, hybridization of banana and glass fiber yields to a much favorable properties condition.
- In depth, analysis of the machinability of banana fiber reinforced epoxy composite and glass fiber reinforced epoxy composite has been performed under both dry and compressed air cooling condition.
- Surface roughness and cutting force are found to improve substantially in compressed air cooling condition for both the developed composite.
- All the process parameters are found to possess significant effect on each responses as determined through ANOVA analysis
- While machining BFRP composite under compressed air cooling condition, the optimum cutting parameters which yielded the output responses (surface roughness and cutting force) ; R_a =2.511 µm, P_z = 15.457 N are follows: 0.403 mm of t, 55 m/min of V_c and 0.116 mm/rev
- Optimum cutting parameters which yielded the R_a =2.030 µm, P_z = 10.501 N are

follows: 0.2 mm of t, 55 m/min of V_c and 0.09 mm/rev while machining GFRP composite under compressed air cooling condition

- For ANN developed model, regression value is found to be 0.99518 for banana fiber reinforced epoxy composite and 0.99796 for glass fiber reinforced epoxy composite which are very close to 1, thus justifying the efficacy of the developed model

Recommendations

i. Experimental work in different natural fiber reinforced composite (pineapple, sisal) can be carried out with different weight percentage and orientation of the fibrous materials. Various orientation can also be introduced to observe the effect of input parameter on their machinability.

ii. Apart from dry and compressed air cooling condition, machining can be performed out under cryogenic cooling environment.

iii. PCD cutting insert can be used to analyze the effect of various parameters

iv. In the present work, a model has been developed based on artificial neural network. ANFIS may also be used to predict various output responses.

v. Response surface methodology has been used in this research work to optimize the cutting conditions. Performance evaluation can also be conducted using Taguchi and Principal component analysis.

References

Abrao A. M., Faria P. E., Campos-Rubio J., Reis P. and Davim J. P., "Drilling of fiber reinforced plastics: a review", Journal of Materials Processing Technology, Vol.186 (1-3) pp.1-7, 2007

Chandramohan D. and Marimuthu K., "Tensile and Hardness Tests on Natural Fiber Reinforced Polymer Composite Material", International Journal of Advanced Engineering Sciences and Technology, Vol. 6(1), pp. 97-104, 2011

Cheung H. Y., Mei P. H. Cardona F. and David H., "Natural fiber-reinforced composites for bioengineering and environmental engineering applications", Composites Engineering, Vol. 40(7), pp. 655- 663, 2009

Choudhury I. A. and El-Baradie M. A., "Surface roughness prediction in the turning of high strength steel by factorial design of experiments", Journal of Materials Processing Technology, Vol. 67(1-3), pp. 55-61, 1997

Dabade U.A. and Dapkekar D., "Modeling of chip-tool interface friction to predict cutting forces in machining of Al/SiC composites", International Journal of Machine Tools and Manufacturing, Vol.49 (9), pp. 690-700, 2009

Dai D. and Fan M., "Wood fibres as reinforcements in natural fibre composites: structure, properties, processing and applications in Natural Fiber Composites: Materials, Processes and Properties", Chapter 1, pp. 3–65, Woodhead Publishing, 2014.

Davim J. P., "Diamond tool performance in machining MMC's", Journal of Materials Processing Technology, Vol.128 (3) pp. 100-105, 2000

Davim J.P., "Design of optimization of cutting parameters for turning metal matrix composites", Journal of Materials Processing Technology, Vol.132 (1-3) pp. 340-344, 2003

Dhieb H., Buijnsters J. G., Eddoumy F., Vázquez L. and Celis J.P., "Surface and Sub-Surface Degradation of Unidirectional Carbon Fiber Reinforced Epoxy Composites Under Dry and Wet Reciprocating Sliding", Composites Part A: Applied Science and Manufacturing, Vol.55 (6), pp. 53-62, 2013

Faruk O., Bledzki A. K., and Sain M., "Bio-composites reinforced with natural fibers", Progress in Polymer Science, Vol. 37 (11), pp. 1552–1596, 2012

Fatima S. and Mohanty A. R., "Acoustical and fire-retardant properties of jute composite materials", Applied Acoustics, Vol. 72 (3), pp. 108–114, 2011

Gallab M. and Sklad M., "Machining of Al/SiC particulate metal matrix composites-part II: work piece surface integrity", Journal of Materials Processing Technology, Vol.83 (1) pp. 277-285, 1998

Ghani M.H. and Ahmad S., "The comparison of water absorption analysis between counterrotating and corotating twin-screw extruders with different antioxidants content in wood plastic composites", Advances in Materials Science and Engineering, Vol. 43 (2), pp. 201-205, 2011

Haneefa A., Bindu P., Aravind I. and Thomas S., "Studies on Tensile and Flexural Properties of Short Banana/Glass Hybrid Fiber", Journal of Composite Materials, Vol.42 (15), pp. 1471-1489, 2008

Hashin Z., “ Analysis of Composite materials: A survey”, Journal of Applied Mechanics, Vol. 50 (3), pp. 481-505, 2009

Hocheng C. and Tsao C., “Effects of special drill bits on drilling-induced delamination of composite materials”, International Journal of Machine Tools and Manufacture, Vol.46 (12-3) pp. 1403-1416,2006

Joseph S., Sreekala M. S., Oommena Z., Koshy P., and Thomas S., “A Comparison of the Mechanical Properties of Phenol Formaldehyde, Composites Reinforced with Banana Fibres and Glass Fibres”, Composites Science and Technology, Vol.62 (14), pp. 1857-1868, 2002

Kaebernick H., Kara S. and Sun M., “Sustainable product development and manufacturing by considering environmental requirements”, Robotics and Computer-Integrated Manufacturing, Vol 19 (6), pp. 461-468, 2003

Kabir M. M., Wang H., and Cardona F., “Chemical treatments on plant-based natural fibre reinforced polymer composites: an overview”, Composites Part B: Engineering, Vol. 43 (7), pp. 2883–2892, 2012

Kannan S., Kishawy H.A. and Balazinski M., “Flank wear progression during machining metal matrix composites”, ASME, Journal of Manufacturing Science and Engineering, Vol.128 (3) pp. 787-791, 2006

Karnik S.R., Gaitonde V.N., Rubio J.C. and Correia A.E., “Delamination analysis in high-speed drilling of carbon fiber reinforced Plastics (CFRP) using artificial neural network model”, Materials and Design, Vol. 29 (9) pp. 1768-1776, 2008

Khalil A., Bhat I. H., Jawaid M., Zaidon A., Hermawan D. and Hadi Y. S., “Bamboo Fibre Reinforced Biocomposites: A Review”, Materials and Design, Vol.42 (12), pp. 353–368, 2012

Khuri A. I., and Mukhopadhyay S., "Response surface methodology", Wiley Interdisciplinary Reviews: Computational Statistics, Vol. 2 (2), pp. 128-149, 2010

Kim K. S., Lee D. G. and Namgung S., "Machinability of carbon fiber-epoxy composite materials in turning", Journal of Materials Processing Technology, Vol.32 (3), pp. 553-570, 1992

Koenig W., Wulf C. H. and Grab P., and Willerscheid H., "Machining o ffiber reinforced plastics", CIRP Annals, Vol. 34 (2), pp. 537-54, 1985

Komanduri R., "Machining of fiber-reinforced composites", Machining Science and Technology, Vol.1(1), pp.113-152, 1997

Koplev A., Lystrup A. and Vorm T., "The cutting process, chips, and cutting forces in machining CFRP,Composites Engineering, Vol.14 (4), pp. 371-376, 1983

Ku H., Wang H., Pattarachaiyakoop N. and M. Trada, "A review on the tensile properties of natural fiber reinforced polymer composites", Composites Part B: Engineering, Vol. 42 (4), pp. 856–873, 2011.

Laban B. G., Nicollier T., Leterrier Y., Lundquist L., and Manson J., "Life Cycle Assessment of Biofibers Replacing Glass Fibers as Reinforcement in plastics", Resources Convertion and Recycling, Vol.33 (4), pp. 267-287, 2001

Lin C. L., "Use of the Taguchi method and grey relational analysis to optimize turning operations with multiple performance characteristics", Materials and Manufacturing Process, Vol.19 (2), pp. 209-220, 2004

Lin J. T., Bhattacharya D. and Lane C., "Machinability of a silicon carbide reinforced aluminum metal matrix composite", Vol.181-182 (1) pp.883-888,1995

Madhukiran J., Rao S. and Madhusudan S., "Fabrication and Testing of Natural Fiber Reinforced Hybrid Composites Banana/Pineapple", International Journal of Modern Engineering Research, Vol.3 (4), pp. 2239-2243,2013

Maleque M. A., Belal F. Y. and Sapuan S. M., "Mechanical Properties Study of Pseudo-Stem Banana Fiber Reinforced Epoxy Composite, The Arabian Journal for Science and Engineering, Vol.32 (2), pp. 359-364, 2007

Manna A. and Bhattacharayya B., "A study on machinability of Al-SiC MMC", Journal of Materials Processing Technology, Vol.140 (1) pp.711-716,2003

May-Pat A., Valadez-González A. and Herrera-Franco P. J., "Effect of fiber surface treatments on the essential work of fracture of HDPE-continuous henequen fiber-reinforced composites", Polymer Testing, Vol. 32 (6), pp. 1114–1122, 2013

Merlini C., Soldi V. and Barra G. M., "Influence of Fiber Surface Treatment and Length on Physico-Chemical Properties of Short Random Banana Fiber-Reinforced Castor Oil", Polyurethane Composites, Polymer Testing, Vol. 30(8), pp. 833–840, 2011

Mohan R. K., Mohana R. K. and Prasad A.V., "Fabrication and testing of natural fibre composites: Vakka, sisal, bamboo and banana", Materials and Design, Vol. 31(1), pp. 508– 513, 2010

Mohanty A. K., Khan M. A., and Hinrichsen G., "Surface modification of jute and its influence on performance of biodegradable jute-fabric/Biopol composites", Composites Science and Technology, Vol. 60 (7), pp. 1115–1124, 2000

Muthukrishnan N., Murugan M. and Rao K. P., "Machinability issues in turning of Al–SiC metal matrix composites", International Journal of Advanced Manufacturing Technology, Vol.39 (3-4) pp.211-218,2008

Mwaikambo L., “Review of the history, properties and application of plant fibers”, African Journal of Science and Technology, Vol. 7 (2), pp. 121, 2006

Nalbant M. and Sur G., “Application of Taguchi method in the optimization of cutting parameters for surface roughness in turning”, Materials and Design, Vol.28 (4), pp. 1379-1385, 2007

Nayak D. and Bhatnagar N., “Machining studies of uni-directional glass fiber plastic composites: effect of geometrical and process parameters”, Machining Science and Technology Vol.9 (4) pp.481–501, 2005

Niana C.Y., Yangb W. H. and Tarng, Y. S., “Optimization of turning operations with multiple performance characteristics”, Journal of Materials Processing Technology, Vol. 95 (1-3), pp. 90-96, 1999

Nishino T., “Kenaf reinforced biodegradable composite”, Composites Science and Technology, Vol 63 (9), pp. 1281-1286, 2003

Noordin M.Y., Venkatesh V. C., Sharif S., Elting S., and Abdullah A., “Application of response surface methodology in describing the performance of coated carbide tools when turning AISI 1045 steel”, Journal of Materials Processing Technology, Vol.145 (1), pp. 46-58, 2004

Palani kumar K., Karunamoothy. L. and Kathikeyan. R., “Assessment of factors influencing surface roughness on machining of Glass fiber reinforced polymer Composites”, Materials and Design, Vol. 27(10) pp. 863-871, 2006

Palanikumar K., Ramesh M. and Reddy K. H., “Comparative Evaluation on Properties of Hybrid Glass Fiber- Sisal/Jute Reinforced Epoxy Composites, Procedia Engineering”, Vol.51 (13), pp. 745-750, 2013

Palanikumar, K. and Karthikeyan R., "Optimal machining conditions for turning of particulate metal matrix composites using Taguchi and response surface methodologies", Machining Science and Technology, Vol.10 (4), pp. 417-433, 2006

Pothan L. A, Thomas S. and Neelakantan N. R., "Short Banana Fiber Reinforced Polyester Composites: Mechanical, Failure and Aging Characteristics", Journal of Reinforced Plastics and Composites, Vol.16 (8), pp. 744-765,1997

Prasanna G. V. and Subbaiah, K. V., "Modification, Flexural, Impact, Compressive Properties & Chemical Resistance of Natural Fibers Reinforced Blend Composites", Malaysian Polymer Journal, Vol.8 (), pp. 38-44,2013

Ramesh M., Atreya T. S. A., Aswin U. S., Eashwar H. and C. Deepa, "Processing and mechanical property evaluation of banana fiber reinforced polymer composites", Procedia Engineering, Vol. 97 (2), pp. 563–572, 2014

Sahin Y. and Motorcu A., "Surface roughness model for machining mild steel with coated carbide tool", Materials and Design, Vol.26 (4), pp 321-326, 2006

Sain M., Park S. H., Suhara F., and S. Law, "Flame retardant and mechanical properties of natural fibre-PP composites containing magnesium hydroxide", Polymer Degradation and Stability, Vol. 83 (2), pp. 363–367, 2004

Shankar P. S., Reddy K.T. and Sekhar V. C., "Mechanical Performance and Analysis of Banana Fiber Reinforced Epoxy Composites", International Journal of Recent Trends in Mechanical Engineering, Vol.1 (5), pp.1-10, 2013

Shalwan A. and Yousif B. F., "In state of art: mechanical and tribological behavior of polymeric composites based on natural fibers", Materials & Design, Vol. 48, pp. 14–24, 2013

Singh D. and Rao P. V., " Optimization of tool geometry and cutting parameters for hard turning", Materials and Manufacturing Processes, Vol. 22 (1), pp. 15-21, 2007

Sreekala M. S. and Thomas S., "Effect of fibre surface modification on water-absorption characteristics of oil palm fibres", Composites Science and Technology, Vol. 63 (6), pp. 861–869, 2003

Srinivasan V. S., Boopathy S. R., Sangeetha D., and Ramnath B. V., "Evaluation of mechanical and thermal properties of banana-flax based natural fibre composite", Materials & Design, Vol. 60 (3), pp. 620–627, 2014.

Sumaila M., Amber I. and Bawa M., "Effect of Fiber Length on the Physical and Mechanical Properties of Random Oriented, Nonwoven Short banana (Musa Balbisiana) Fiber/Epoxy Composite", Asian Journal of Natural & Applied Sciences, Vol. 2 (1), pp. 39-49, 2013

Suardana N. P., Ku M. S., and Lim J. K., "Effects of diammonium phosphate on the flammability and mechanical properties of bio-composites", Materials & Design, Vol. 32 (4), pp. 1990–1999, 2011.

Takeyama H. and Iijima N., "Machinability of glass fiber reinforced plastics and application of ultrasonic machining", Annals of CIRP, Vol.37 (1) pp.93-96, 1988

Tawakkal M. A., Cran M. J., and Bigger S. W., "Effect of kenaf fibre loading and thymol concentration on the mechanical and thermal properties of PLA/kenaf/thymol composites", Industrial Crops and Products, Vol. 61 (4), pp. 74–83, 2014

Thiruchitrambalam M.., Alavudeen A., and Elaya A., "Improving mechanical properties of banana/kenaf Polyester hybrid composites using sodium laulryl Sulfate treatment", Materials Physics and Mechanics, Vol. 8 (8), pp. 165-173, 2009

Venkateshwaran, N., Elaya P. Alavudeen A, and Thiruchitrambalam A., "Mechanical and water absorption behaviour of banana/sisal reinforced hybrid composites", Materials and Design, Vol. 32 (7), pp. 4017-4021, 2011

Venkateshwaran, N., Elaya P. and Jagatheeshwaran A., "Effect of fiber length and fiber content on mechanical properties of banana fiber/epoxy composite", Journal of Reinforced Plastics and Composites, Vol. 30 (19), pp. 1621-1627, 2011

Wern C. W. and Ramulu M., "Influence of fibre on the cutting stress state in machining idealized glass fibre composite", Journal of Strain Analysis, Vol. 32 (1) pp. 19-26, 1997

Zhong Z. W., Khoo L. P. and Han, S. T., "Prediction of surface roughness of turned surfaces using neural networks", Int. J. Adv. Manuf. Technol., Vol.28 (4), pp. 688-693, 2006