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Optimizations of machining constraints on GFRP composites by concern task analysis using Taguchi method

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Abstract

Nowadays, glass fiber reinforced plastics (GFRP) composites play a vital role in many engineering applications as an alternative to various heavy exotic materials. In GFRP polymeric composites, the matrix of polymer (resin) is reinforced with glass fibers. Glass fiber reinforced plastics are increasingly used for variety of engineering applications from automobile to air craft components because of their superior advantages when compared to the other engineering materials. The advantages include weight-to-strength ratio, high fracture toughness and excellent thermal and corrosion resistance. Though the technology of composite manufacturing is advanced, near-net-shaped components with the required surface finish quality can be achieved only by machining. Surface quality and dimensional precision will greatly affect the parts during their useful life, especially in cases where the components will be in contact with other elements or materials during their useful life. Therefore, their study and characterization is extremely important.

Keywords: Optimization, Taguchi method, Composites

1. Introduction

The application filed of FRP composites, expands the opportunity of machining such as cutting off, drilling, milling, turning etc, has increased for its fabrication. However, the users of FRP have faced difficulties to machine it, because knowledge and experience acquired for conventional materials cannot be applied to such new materials, of which machinability is completely different from that of conventional materials.

Generally, composite materials are engineered materials and are made from two or more constituent materials with significantly different physical and chemical properties. The two types of constituent phases are matrix and reinforcement.

Generally, most materials, especially brittle ones, exhibit an important characteristic that a small-diameter shape is much stronger than the bulk material. This feature has been taken as an advantage in FRPs. The fiber therefore can provide the key structural properties such as high specific strength and stiffness for FRPs, while the polymer matrix provide support to the fiber and also transmit the load to the fibers and protect them from harsh environment. These materials could meet the requirements of modern technology, not met by the conventional materials.

1.2 Large particle Reinforced composites

Large particle and dispersion-strengthened composites are the two subclassifications of particle-reinforced composites. The distinction between these isb ased upon reinforcement or strengthening mechanism. The term “large” is used toindicatethatparticle-matrixinteractionscannotbetreatedontheatomicormolecularlevel.For most of these composites, the particle phase is harder and stiffer than thematrix.Thesereinforcingparticlestendtoretainthemovementofthematrixphaseinthevicinityofeachparticle.

1.2.1 Dispersion strengthened composites

Fordispersion-strengthenedcomposites,particlesarenormallymuchsmaller,having diameter between 0.01 and 0.1 µm. Particle-matrix interactions that lead tostrengtheningoccursattheatomicormolecularlevel.Matrixbearsthemajorportionofanappliedload,andthesmalldispersedparticleshinderthemotionofdislocations.Thus plastic deformation is restricted so that yield and tensile strengths, as well as hardness are improved. A composite is a structural material which consists of combining two or more constituents. The constituents are combined at a macroscopic level and are not soluble in each other. One constituent phase is called the reinforcing phase and the one in which it is embedded is called the matrix. The reinforcing phase may be in the form of fibers, particles or flakes. The design goals of fiber reinforced composites often include highstrength and or stiffness on a weight basis. These characteristics are expressed in terms of specific strength and specific modulus parameters, which correspond respectively, to the ratio of tensile strength to specific gravity and modulus of elasticity to the specific gravity.

2. Literature Review

Everstine and Rogers [23] proposed an analytical theory of machining FRP composites, they developed a theory of plane deformation of incompressible composites reinforced by strong parallel fibers.

Takeyama and Lijima [20] carried out the ultrasonic machining of GFRP in orthogonal cutting with varied fiber angles. In their study, they described that the chip formation process for GFRP materials is strongly governed by the fiber orientation with reference to the cutting direction.

Bhatnagar et al [2], 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, the selection of cutting parameters and the cutting tools are dependent on the type of fiber used in the composites and which is very important in the machining process.

Santhana Krishnan [24] studied the mechanism of material removal during GFRP machining and the type of wear in high-speed steel tools with the help of scanning electron microscope.

Lee [25] investigated an experimental study on the machinability of GFRP by means of tools made of various materials and geometries. Wang and Zhang [26] investigated the machinability of epoxy composites reinforced by unidirectional carbon fiber materials when subjected to orthogonal cutting and found that the subsurface damage and its mechanisms of machined components are greatly influenced by fiber orientation.

Davim and Mata [27] studied the machinability in turning processes of FRPs using polycrystalline diamond cutting tools. In their study, controlled machining experiments were performed with cutting parameters prefixed in the work piece. A statistical technique, using orthogonal arrays and analysis of variance, was employed to investigate the influence of cutting parameters on specific cutting pressure and surface roughness.

Fereirra et al. [28] proved that a diamond tool will produce a good surface finish, as it is produce low surface roughness with minimum tool wear.

Rahman et al.[29] conducted machining studies on a carbon fiber reinforced plastic (CFRP) composite using various advanced cutting tools and found that PCD tools exhibited high wear resistance.

Chungshin chang et al. [30] performed turning on high strength GFRP material with carbide tool to study the temperature of tip surface and cutting forces and a comparison was made between experimental values and FEA model developed by them. They conclude that, the experimental values are very nearer to the model results.

Palanikumar et al. [35] have studied the effect of cutting parameters on surface roughness on the machining of GFRP composites by PCD tool by developing a second order model for predicting surface roughness.

Konig and Grab [36] studied the main parameters concerning machining quality, specially surface roughness and material damage in drilling fiber reinforced thermosets.

Spur and Wunsch [37] have found that during the turning of GFRP composites surface roughness increases with an increase in the feed rate but had no dependence on the cutting velocity.

Kaneeda [38] observed the surface roughness in relation to the fiber direction and chip generation using an orthogonal cutting device, and studied the analysis of the GFRP cutting mechanism by the cutting force. Most of the studies on GFRP composite machining shows that minimizing the surface roughness was a serious task so that, the machining of FRP is an area still with full of open question [39]. In order to know surface quality and dimensional properties, it is necessary to employ theoretical models for prediction purpose.

Naveen Sait et al. [40], analyzed the influence of machining parameters on GFRP filament wound and hand lay-up pipes. The effect of machining parameters on tool wear, surface roughness and cutting forces are evaluated.

John Kechagias et al. [41] have investigated surface texture parameters during the turning of fiber reinforced composites. Based on the statistical analysis of the experimental results it was found that the arithmetic mean roughness, the maximum peak to valley and the fractal dimension depend mainly on the feed rate parameter.

Abdul Budan and Vijayarangan [42] performed drilling experiments on bi- directional GFRP composite laminate using high speed drill tools to verify the effect of machining parameters and fiber concentration on surface finish and hole quality and delamination. Their experiments results reveals that, the surface roughness and hole diameter variation can be controlled with drill speed, feed rate and fiber content.

Ramesh et al. [47] developed a mathematical model using finite element method for machining of FRP. They carried out the analysis for four different FRP materials with four fiber orientation angles.

Naveen Sait et al. [48] made an attempt to investigate the performance of K20 grade cemented carbide tool on machining of GFRP pipes. Effect of machining parameters on tool wear and cutting forces are studied.

Abdul Budan [49] has developed a 2- D FEA model to analyze the effect of fiber proportion and orientation on cutting forces. He concluded that, fiber orientation of 450 and 600 have shown favorable results. The principal cutting force obtained during machining of GFRP composite materials is considerably lower than that on machining steel [50, 51]. This is due to the difference in composition of GFRP material, its amorphous nature, and the soft condition of the matrix material.

Venugopal Rao et al. [52] has simulated the orthogonal machining of Uni- directional carbon finer reinforced polymer (UD-CFRP) composites using Finite Element Method (FEM). The cutting force during orthogonal machining work was studied experimentally and numerically for a range of fiber orientation (θ), depth of cut and tool rake angles. They found that cutting force varies with fiber orientation angle and depth of cut.

Sahraie Jahromi and Bahr [53] have concluded that, chip-formation mechanism in orthogonal machining of composites is different from that of metals, the cutting theories developed for metals cannot be directly used for orthogonal machining of composites. They have developed a new analytical method using energy method to predict the machining forces for orthogonal machining of unidirectional polymer–matrix composites (PMCs) for fiber orientations ranging from 90° to 180°. Sreejith et al. [54] have investigated the machining of carbon/phenolic composites using PCBN tools. They have identified critical range of speed and temperature at which specific cutting pressure is almost steady. The specific cutting pressure was chosen as a process indicator to determine the machinability of FRP composite material. It is usually influenced by the cutting speed and material.

3. Materials and Methods

3.1 Properties of Cement

The basic turning operation is one of the most commonly employed operation in metal cutting process. The work material is fixed in the chuck of a lathe and rotated. The tool is held rigidly in a tool post and moved at constant rate along the axis of the bar, removing a layer of metal to form cylinder or surface of more complex profile. This is shown diagrammatically in Figure 3.1.

Turning is an important operation in which a single point cutting tool removes the material from the cylindrical work piece. The performance of Glass Fiber Reinforced Plastic (GFRP) composites in turning has been studied by conducting various machinability tests. Different kinds of cutting tool inserts are used for machining the work material. The experiments have been planned using Taguchi's orthogonal array in the Design of Experiments (DOE), which helps in reducing the number of experiments. The machinability testing experiments are conducted according to a 5-level L25 orthogonal array. Here, the level indicates factor's level.

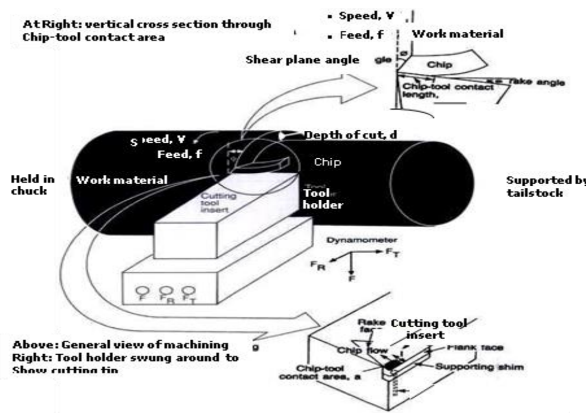

Figure 1:A detailed turning operation

3.1.1 Design Of Experiments

Designofexperiments(DOE)isasystematic,rigorousapproachtosolveengineering problems, which applies principles and techniques at the data collection stage so as to ensure the generation of valid, defensible, and supportable engineeringc conclusions of the manufacturing process. It also has an extensive application in the development of a new process.

This information is used to estimate the settings of factors to achieve maximum output. Confirmation consists of gathering data to verify a hypothesis about a relationship among variables. The application of experimental design is useful in all the above phases. A well-designed experiment can ensure the following:

1. Improved process output.
2. Reduced variability and closer conformance to nominal or target requirement.
3. Reduced development time.
4. Reduced overall cost.

Traditional approach of experimental design is empirical in nature. In this approach, one factor is varied at a time while keeping all the other factors constant. This full factorial design is time-consuming and consists of a number of experimental trials. Since only one variable is changed at a time, it completely misses its interaction effects too.

Figure 2: Photograph of the tool holder

3.1.2 Taguchi's design of experiments

Taguchi techniques have been used widely in engineering design [113]. The main thrust of the Taguchi technique is the use of parameter design, which is an engineering method for product or process design that focuses on determining the parameter (factor) settings for producing the best levels of a quality characteristic (Performance measure) with minimum variation. Taguchi design provides a powerful and efficient method for designing the processes that operate consistently and optimally over a variety of conditions. The best design requires the use of strategically designed experiments, which expose the process to various levels of design parameters.

4. Experimental Setup and Procedure

The typical assembling of the different parts is done as shown in To simulate the best possible numerical behavior as like experiment the two steel loading plates are modeled at the location of two loading points. The tie constraint is defined between the loading plate and the top surface of beam. The loading plate is also constrained as rigid body. The allocation of reinforcement is made in such a way that an effective cover of 20mm at tension face and 20mm at compression face of the beam is assured. The interaction between the concrete beam and reinforcing steel is definedas" embedded region" constraint. The embedded element technique is used to specify that an element or groupsofelementsareembeddedinhostelements.ABAQUSsearchesforthegeometricrelationships between nodes of the embedded elements and the host elements. If a node of an embedded element lies within a host element, the translational degrees of freedom at the node are eliminated and the node becomes an "embedded node".

5. Conclusions

- In machining of GFRP composites the surface roughness is highly influenced by feed followed by cutting speed and fiber orientation angle. Depth of cut has very little effect on surface roughness.
- Surface roughness increases with increasing the feed rate and decreases with increasing the cutting speed.
- Cutting forces are highly influenced by feed, followed by cutting speed and fiber orientation angle. In this case also depth of cut has very little effect on cutting force in machining GFRP composites.
- The chips obtained, during GFRP composite machining, are almost in complete fine powder like dust form.

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