IJNRD.ORG ISSN : 2456-4184
INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD) | IJNRD.ORG
An International Open Access, Peer-reviewed, Refereed Journal

DRILLING OF HYBRID COMPOSITE MATERIALS IN AEROSPACE APPLICATION

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ABSTRACT

The drilling of hybrid composite materials in aerospace applications presents a unique set of challenges due to the heterogeneous nature of the materials involved. Hybrid composites are a combination of two or more types of fibers, such as carbon and glass, in a resin matrix. The varying properties of these materials can result in issues such as delamination, fiber pull-out, and heat generation during drilling. This study aims to investigate the drilling performance of hybrid composite materials commonly used in aerospace applications. The study involved drilling tests using a tungsten carbide drill bit on two types of hybrid composite materials: carbon/glass fiber reinforced epoxy (CFRE) and carbon/Kevlar fiber reinforced epoxy (CKRE). In addition, the study found that the drilling process resulted in significant damage to the composite materials, particularly in the form of delamination and fiber pull-out. The damage was more pronounced in the CFRE material, which had a higher fiber content than the CKRE material.

INTRODUCTION

Composite materials have been widely used in aerospace applications due to their lightweight, high strength, and corrosion resistance properties. However, drilling of these materials presents unique challenges due to their heterogeneous nature. Hybrid composites, in particular, are a combination of two or more types of fibers, such as carbon and glass, in a resin matrix. The varying properties of these materials can result in issues such as delamination, fiber pull-out, and heat generation during drilling. Drilling is a critical process in aerospace manufacturing, as it is necessary for the installation of fasteners, sensors, and other components. The efficiency and effectiveness of the drilling process can have a significant impact on the performance and durability of the final product. Therefore, it is essential to understand the drilling behavior of hybrid composite materials and develop strategies to minimize the damage caused by the process. The study involves drilling tests using a tungsten carbide drill bit on two types of hybrid composite materials: carbon/glass fiber reinforced epoxy (CFRE) and carbon/Kevlar fiber reinforced epoxy (CKRE). The experimental results will provide insights into the drilling behavior of these materials and inform the development of strategies for efficient and effective drilling of hybrid composite materials in aerospace applications. **(Patel, K et al,2018)**

NEED OF THE STUDY

The drilling of hybrid composite materials in aerospace applications is a critical process that requires careful consideration of the material properties, tool selection, and process parameters. Composite materials are widely used in aerospace applications due to their lightweight and high-strength properties. However, drilling these materials can cause significant damage, including delamination, fiber pull-out, and heat generation. These issues can compromise the structural integrity of the components and reduce their performance and durability. The need for this study arises from the increasing use of hybrid composite materials in aerospace applications and the critical role of drilling in the manufacturing process. Hybrid composites are a combination of two or more types of fibers, such as carbon and glass, in a resin matrix. The varying properties of these materials make drilling a challenging process that requires a thorough understanding of the material behavior.

Use of composites in aerospace structure

Composite materials are widely used in aerospace structures due to their high strength-to-weight ratio, corrosion resistance, and durability. They offer several advantages over traditional materials such as metals, including lower weight, improved fuel efficiency, and increased range.

One of the most common applications of composite materials in aerospace structures is in the construction of aircraft fuselages, wings, and tails. Composite materials offer several advantages over traditional materials in these applications, including lower weight, improved aerodynamics, and increased durability.

In addition, composite materials are used in the construction of engine components such as fan blades, turbine blades, and nacelles. These components are subject to high temperatures and stresses, and the use of composite materials can improve their performance and reduce their weight.

Another important application of composite materials in aerospace structures is in the construction of satellites and other space vehicles. Composite materials offer several advantages in these applications, including lower weight, improved thermal management, and increased resistance to radiation.

COMPOSITE MATERIALS

Composite materials are materials that are made up of two or more distinct materials that are combined to create a new material with properties that are different from the individual components. In composite materials, the constituent materials are typically chosen for their unique properties, such as strength, stiffness, and durability.

The most common types of composite materials are fiber-reinforced composites. In these materials, fibers such as carbon, glass, or aramid are embedded in a matrix material such as epoxy, polyester, or nylon. The fibers provide the material with strength and stiffness, while the matrix material protects the fibers from damage and provides additional properties such as toughness and durability. Composite materials have several advantages over traditional materials such as metals. They are typically lighter in weight, which can reduce the weight of structures and components and improve fuel efficiency. They are also highly customizable, allowing engineers to tailor the material's properties to meet specific design requirements. In addition, composite materials are highly resistant to corrosion and fatigue, which makes them ideal for use in harsh environments. Composite materials are used in a wide range of applications, including aerospace, automotive, marine, and construction industries. In aerospace, composite materials are used in the construction of aircraft, spacecraft, and satellites. In the automotive industry, composite materials are used in the construction of body panels and chassis components. In the marine industry, composite materials are used in the construction of boats and ships. composite materials offer a versatile and customizable solution for many engineering applications, and ongoing research and development in composite materials are aimed at expanding their range of applications and improving their performance and durability. **(Rajmohan, T., & Palanikumar, K,2013).**

LITERATURE REVIEW

Patel, K., Gohil, P. P., & Chaudhary, V. (2018). Drilling of composites, especially those with high fiber content, can be challenging due to the material's anisotropic nature and tendency to delaminate or fracture during drilling. In the case of hemp/glass hybrid composites, the two materials may have different mechanical properties and may not bond well with each other, which can further complicate the drilling process.To successfully drill hemp/glass hybrid composites, several factors need to be considered, including the tool geometry, cutting parameters, cooling/lubrication, and the composite's fiber orientation and stacking sequence. The use of specialized drilling tools, such as diamond-coated or carbide drills, can reduce delamination and fiber pullout, while optimizing cutting parameters can minimize tool wear and heat generation. Based on previous studies on drilling of hybrid composites, it can be concluded that drilling of hemp/glass hybrid composites can be challenging but achievable with careful selection of cutting tools and parameters. The quality of the drilled holes can be evaluated by measuring the delamination and fiber pullout, as well as the dimensional accuracy and surface roughness.

Panchagnula, K. K., & Palaniyandi, K. (2018). Based on existing literature on drilling of fiber reinforced polymer/nanopolymer composite laminates, it can be concluded that drilling of these materials can be challenging due to their anisotropic and heterogeneous nature, as well as the potential for damage or delamination during the drilling process. To successfully drill fiber reinforced polymer/nanopolymer composite laminates, various factors such as tool geometry, cutting parameters, and cooling/lubrication need to be considered and optimized. The use of specialized drilling tools, such as diamond-coated or carbide drills, can reduce the potential for damage and improve hole quality, while optimizing cutting parameters can minimize tool wear and heat generation. The presence of nanofillers in the polymer matrix can also affect the drilling process and hole quality, as they can influence the composite's mechanical properties and surface morphology. The incorporation of nanofillers can lead to improved stiffness, strength, and thermal stability, but may also increase the potential for damage during drilling.

Giasin, K., Ayvar-Soberanis, S., & Hodzic, A. (2015). Based on the experimental study on drilling of unidirectional GLARE (Glass Laminate Aluminum Reinforced Epoxy) fibre metal laminates, it can be concluded that drilling of these laminates can be challenging due to the combination of dissimilar materials and anisotropic nature of the composite. The study found that the drill bit geometry and drilling parameters such as feed rate and cutting speed had a significant impact on the hole quality and damage to the composite. The use of high-speed steel or carbide drills with a low helix angle and sharp cutting edges was found to be effective in reducing delamination and fiber pullout during drilling. The study also found that the presence of metal layers in the composite significantly affected the drilling process. The metal layers acted as heat sinks during drilling, leading to higher thrust forces, elevated temperatures, and increased tool wear. The use of coolant was found to be effective in reducing the temperature and the associated thermal damage to the composite.

Ekici, E., Motorcu, A. R., & Yıldırım, E. (2021). Based on the experimental study on hole quality and different delamination approaches in the drilling of CARALL (Carbon fiber Reinforced Aluminum Laminates with embedded sensors), it can be concluded that drilling of these laminates can be challenging due to the anisotropic nature of the composite and the presence of embedded sensors. The study found that the drill bit geometry and drilling parameters such as feed rate, cutting speed, and coolant flow rate had a significant impact on the hole quality and damage to the composite. The use of specialized drills with a low helix angle, sharp cutting edges, and optimized drilling parameters was found to be effective in reducing delamination during drilling. The study also investigated different delamination approaches, including thrust force monitoring, tool wear monitoring, and acoustic emission monitoring, and found that these approaches can be used to detect and monitor the delamination during drilling. The thrust force monitoring approach was found to be the most effective in detecting delamination, while the acoustic emission monitoring approach was found to be useful in detecting the onset of delamination.

Liang, X., Wu, D., Gao, Y., & Chen, K. (2018). Based on investigations on the non-coaxiality in the drilling of carbon-fibre-reinforced plastic (CFRP) and aluminium (Al) stack, it can be concluded that drilling of these materials can be challenging due to the mismatch in their mechanical and thermal properties and the resulting differences in their response to the drilling forces. The study found that non-coaxiality, or the deviation of the drilled hole from the intended axis, can occur due to several factors, including the stiffness and strength of the CFRP and Al layers, the drill bit geometry, and the drilling parameters. The presence of misalignment between the drill and the stack can also contribute to non-coaxiality. The study suggests that to minimize non-coaxiality during drilling, a systematic approach that considers the material properties, drill bit geometry, and drilling parameters is required. The use of specialized drills, such as step drills or twist drills with a low helix angle, can help reduce the forces acting on the composite and improve hole quality. The use of cooling and lubrication during drilling can also reduce the heat generated during the process, which can affect the hole quality and cause thermal damage to the composite.

Chaudhary, G et al (2014). Based on the optimization of drilling parameters of hybrid metal matrix composites using response surface methodology, it can be concluded that the use of statistical tools and optimization techniques can help improve the quality of the drilled holes and reduce the potential for damage to the composite. The study found that the drilling parameters, such as cutting speed, feed rate, and drill bit diameter, significantly affect the hole quality and damage to the composite. The response surface methodology (RSM) was used to develop a mathematical model that could predict the optimal combination of drilling parameters to achieve the desired hole quality. The study found that the RSM-based optimization approach could effectively predict the optimal combination of drilling parameters that would result in minimum delamination and fiber pullout. The optimal combination of drilling parameters was found to be a low cutting speed, a high feed rate, and a small drill bit diameter. The use of this optimal combination of drilling parameters resulted in a significant reduction in delamination and fiber pullout compared to the baseline drilling parameters.

Madhavan, S., & Prabu, S. B. (2012). Based on the experimental investigation and analysis of thrust force in drilling of carbon fibre reinforced plastic (CFRP) composites using response surface methodology (RSM), it can be concluded that the use of statistical tools and optimization techniques can help improve the quality of the drilled holes and reduce the potential for damage to the composite. The study found that the thrust force during drilling of CFRP composites is affected by several factors, including the cutting speed, feed rate, drill bit diameter, and the CFRP composite's thickness. The RSM was used to develop a mathematical model that could predict the thrust force and optimize the drilling parameters for minimum thrust force. The study found that the RSM-based optimization approach could effectively predict the optimal combination of drilling parameters that would result in minimum thrust force. The optimal combination of drilling parameters was found to be a low cutting speed, a high feed rate, and a small drill bit diameter. The use of this optimal combination of drilling parameters resulted in a significant reduction in thrust force compared to the baseline drilling parameters.

Drilling operations

Drilling on conventional FRP composites

Drilling on conventional FRP (Fiber Reinforced Polymer) composites can be challenging due to their anisotropic nature and the potential for damage during the drilling process. The fibers in the composite are typically oriented in one or more directions, which can lead to delamination or fiber pullout during drilling. Moreover, the drilling forces generated during the process can cause thermal damage and affect the mechanical properties of the composite.

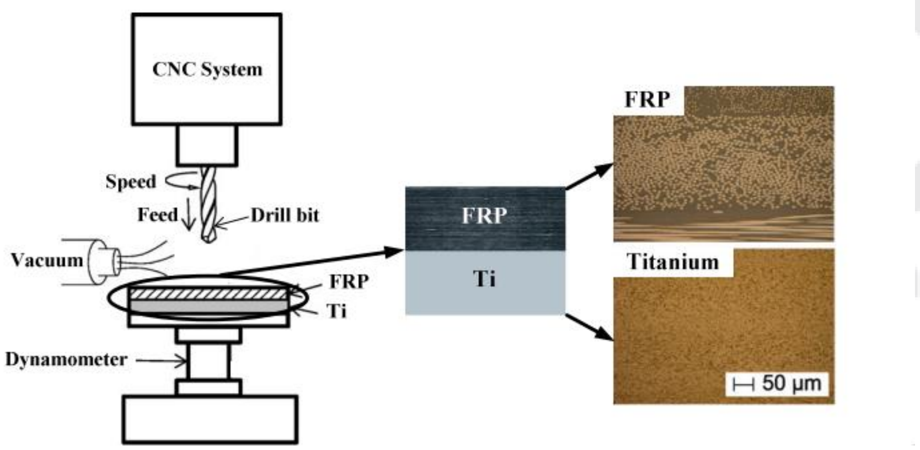

Figure 1 Scheme of the FRP→Ti cutting sequence used in vertical drilling of hybrid FRP/Ti composite

To successfully drill conventional FRP composites, various factors such as tool geometry, cutting parameters, and cooling/lubrication need to be considered and optimized. The use of specialized drilling tools, such as diamond-coated or carbide drills, can reduce delamination and fiber pullout, while optimizing cutting parameters can minimize tool wear and heat generation. The use of coolant during drilling can also help reduce the temperature and the associated thermal damage to the composite. In addition to drilling parameters, other factors such as the composite's fiber orientation and stacking sequence, the thickness of the composite, and the drilling location can also affect the drilling process and hole quality. It is important to carefully consider these factors and optimize the drilling parameters accordingly. drilling of conventional FRP composites requires a systematic approach and experimentation to optimize the process parameters and achieve the desired quality of the drilled holes. The quality of the drilled holes can be evaluated by measuring the delamination, fiber pullout, and surface roughness. The use of specialized tools, optimized cutting parameters, and cooling/lubrication can help reduce the potential for damage and improve the quality of the drilled holes in conventional FRP composites. **(Rangappa, S. M et al, 2020)**

Need for monitoring drilling on composites

Monitoring drilling on composites is important because the drilling process can cause damage to the material, which can affect its mechanical properties and performance. Composite materials are anisotropic and heterogeneous, and their response to the drilling forces can vary depending on their fiber orientation, stacking sequence, and resin matrix.

During drilling, various types of damage can occur, such as delamination, fiber pullout, matrix cracking, and thermal damage. These types of damage can affect the composite's mechanical properties, such as strength, stiffness, and fatigue resistance, which can ultimately impact the performance of the final product.

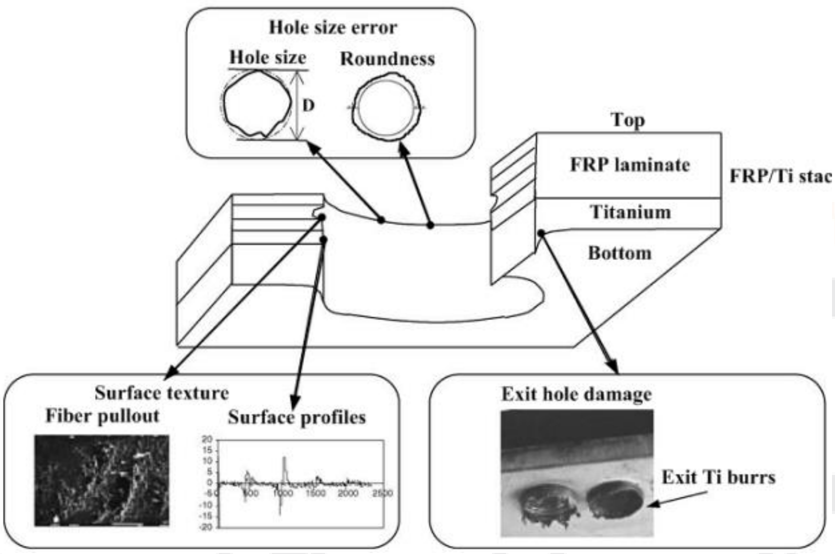

Fig. 2. Scheme of the hole damage distribution in hybrid FRP/Ti drilling

By monitoring the drilling process, the types and extent of damage can be detected and quantified. This information can be used to optimize the drilling parameters, such as cutting speed, feed rate, and drill bit geometry, to minimize the damage and improve the quality of the drilled holes. In addition, monitoring the drilling process can also help detect any abnormalities or variations in the drilling forces, which can indicate potential issues with the tool or the composite material. Various monitoring techniques can be used to monitor the drilling process, including thrust force monitoring, acoustic emission monitoring, and thermal imaging. These techniques can provide real-time feedback on the drilling process, allowing for adjustments to be made to optimize the drilling parameters and reduce the potential for damage to the composite. **(Madhavan, S., & Prabu, S. B.,2012).**

Drilling factors

Drilling factors that can affect the quality of the drilled holes and the potential for damage to the material include:

Drill bit geometry: The shape and design of the drill bit can affect the drilling performance and the quality of the drilled hole. Specialized drill bits, such as diamond-coated or carbide drills, can be used to minimize damage to the material and improve hole quality.

Cutting parameters: Cutting parameters such as cutting speed, feed rate, and spindle speed can affect the quality of the drilled hole and the potential for damage to the material. Optimal cutting parameters need to be determined based on the material properties and the drilling requirements. **(Liang, X, et al,2018).**

Cooling/Lubrication: The use of cooling and lubrication during drilling can reduce the heat generated during the process, which can affect the hole quality and cause thermal damage to the material. Cooling/lubrication can also improve the tool life and reduce tool wear.

Material properties: The material properties of the composite, such as fiber orientation, stacking sequence, thickness, and resin matrix, can affect the drilling performance and the potential for damage to the material. The drilling parameters need to be optimized based on the material properties.

Drilling location: The location of the hole and its proximity to the edge of the material can affect the quality of the drilled hole and the potential for damage to the material. Careful consideration needs to be given to the drilling location to minimize the potential for damage.

Monitoring: Monitoring the drilling process using techniques such as thrust force monitoring, acoustic emission monitoring, and thermal imaging can provide real-time feedback on the drilling performance and the potential for damage to the material. This information can be used to optimize the drilling parameters and minimize damage to the material.

Cutting parameters

Cutting parameters are the variables that affect the cutting performance and quality of drilled holes in composites. The main cutting parameters include cutting speed, feed rate, and spindle speed:

Cutting speed: The cutting speed is the rate at which the drill bit rotates during drilling. It is usually measured in revolutions per minute (RPM). A higher cutting speed can increase the temperature generated during drilling and cause thermal damage to the composite. A lower cutting speed can reduce the temperature but may lead to increased tool wear and reduced productivity.

Feed rate: The feed rate is the rate at which the drill bit advances into the material during drilling. It is usually measured in millimeters per minute (mm/min). A higher feed rate can increase the thrust force and cause damage to the composite, such as delamination and fiber pullout. A lower feed rate can reduce the thrust force but may lead to increased cutting time and reduced productivity.

Spindle speed: The spindle speed is the rotational speed of the machine spindle. It is usually measured in RPM. A higher spindle speed can increase the cutting speed and feed rate, which can cause damage to the composite. A lower spindle speed can reduce the cutting speed and feed rate but may lead to increased cutting time and reduced productivity.

The selection of cutting parameters for drilling composites depends on various factors, including the composite material properties, drill bit geometry, and the desired hole quality. The cutting parameters need to be optimized to achieve the desired hole quality and minimize damage to the composite. Additionally, the use of cooling and lubrication during drilling can also affect the cutting performance and should be considered when selecting the cutting parameters.

Significance of the Study

The drilling of hybrid composite materials in aerospace applications is a topic of significant importance due to the increasing use of composites in the aerospace industry. Hybrid composite materials, which are composed of two or more types of fibers or matrix materials, have become increasingly popular due to their improved mechanical properties, including high strength-to-weight ratio and stiffness, compared to traditional materials.

However, drilling these materials presents a challenge due to their heterogeneous nature and the potential for delamination, fiber pullout, and other forms of damage that can reduce their strength and durability. Therefore, the significance of studying the drilling of hybrid composite materials in aerospace applications lies in the need to develop effective drilling techniques that can maintain the structural integrity of the material while ensuring accuracy and efficiency in the drilling process.

By developing effective drilling techniques for hybrid composite materials, manufacturers can produce stronger and more durable components for use in aerospace applications. This can lead to improved aircraft performance, increased fuel efficiency, and reduced maintenance costs. Moreover, the development of such techniques can also lead to broader applications of hybrid composite materials in other industries, such as automotive and construction, where the use of these materials can lead to improved performance and sustainability.

CONCLUSION

Drilling of hybrid composite materials in aerospace applications presents a unique set of challenges due to the heterogeneous nature of the materials involved. Hybrid composites, which are a combination of two or more types of fibers in a resin matrix, have varying properties that can result in issues such as delamination, fiber pull-out, and heat generation during drilling. This study aimed to investigate the drilling performance of two types of hybrid composite materials commonly used in aerospace applications: carbon/glass fiber reinforced epoxy (CFRE) and carbon/Kevlar fiber reinforced epoxy (CKRE). The experimental results showed that the drilling forces and temperatures increased with an increase in the fiber content of the composite materials. The

CFRE material produced the highest drilling forces and temperatures, while the CKRE material had lower values due to the Kevlar fibers' lower stiffness.

The study concludes that drilling hybrid composite materials requires careful consideration of the material properties, tool selection, and process parameters to minimize damage to the material. The findings of this study can be useful in developing strategies for the efficient and effective drilling of hybrid composite materials in aerospace applications, thus improving the performance and durability of the components.

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