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Extended Abstract

Finite element analysis and simulation study on micromachining of hybrid composite stacks using Micro Ultrasonic Machining process

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Abstract

Hybrid composites stacks are multi-material laminates which find extensive applications in industries such as aerospace, automobile, and electronics and so on. Most hybrid composites consist of multiple layers of fiber composites and metal sheets stacked together. These composite stacks have excellent physical and mechanical properties including high strength, high hardness, high stiffness, excellent fatigue resistance and low thermal expansion. Micromachining of these materials require particular attention as conventional methods such as micro-drilling is extremely challenging considering the non-homogeneous structure and anisotropic nature of the material layers. Micro Ultrasonic Machining (μUSM) is a manufacturing process capable of machining such difficult-to-machine materials with ultraprecision. Experimental study showed that μUSM process could successfully machine hybrid composite stacks at micron scale with a relatively good surface finish. This research uses finite element simulation technique to investigate the material removal during the μUSM process for micromachining hybrid composite stacks. The effects of critical process parameters including the amplitude of vibration, feed rate and tool material on the cavity depth, cutting force and equivalent stress distribution are studied. The outcome of this research can be utilized to further our understanding of performing precision machining of hybrid composite stacks for use in several critical engineering applications.

Fiber reinforced polymers (FRP) are composites of high-strength fibers embedded in a matrix of polymer material. The fibers are generally made of materials such as carbon fiber, glass fiber, basalt or aramid which have high strength, high stiffness and low density. FRPs have several advantages including low-cost, corrosion resistance, lightweight, inherent durability, high strength, eco-friendly, and biodegradability. These properties make FRPs ideal choice of material for several applications including aerospace, automobile, construction, medical technologies and so on. Among the various FRPs, Carbon Fiber Reinforced Polymer (CFRP) has gained particular attention due to its high strength-to-weight ratio, excellent fatigue resistance, high dimensional stability, low thermal expansion, and excellent tensile strength. However, CFRP materials have several limitations including low strength in specific directions considering its anisotropic nature, high susceptibility to fracture due to its brittleness and low wear resistance. To overcome the limitations, FRPs are often stacked with metal alloys to form multi-layers of hybrid composite stacks. The addition of thin layers of metal alloys to FRPs enhances their ability to resist high impact loads and improve the elastic modulus without a significant increase in weight. These hybrid composite stacks have been increasingly popular and are used as an attractive alternative for traditional composites and metal alloys. Studies have reported as much as 35% reduction in mass of the structure by replacing metals and metal alloys with hybrid composite stacks. CFRP composites stacked with thin layers of lightweight metals such as Copper (Cu), Aluminum (Al), Titanium (Ti) and their alloys have been identified as an innovative material for several critical engineering applications. The CFRP metal stacks exhibit high load-bearing capability and excellent impact and shock resistance. The fuselage, wings and tail-plane components of modern day aircraft including Airbus A380 or Boeing 787 contain stacks of hybrid composite metal stacks such as CFRP, CFRP/Ti, and CFRP/Al and so on. The addition of thin layers of metals or metal alloys on CFRP enhances the structure's ability to withstand high mechanical loads, resulting in increased strength-to-weight ratio and thereby reducing the fuel consumption. Some of the other critical applications of CFRP metal stacks include modern automobiles where CFRP/Al stack is used for exterior body components, rotor blades of helicopters consisting of CFRP/Al stacks and so on. Most of the applications mentioned here require machining or drilling of the hybrid composite metal stacks to the required precision. In the past, there have been several attempts on drilling hybrid stacks such as CFRP/Ti and CFRP/Al through conventional drilling in a single shot operation. However, most of these studies have reported difficulties associated with the drilling operation including low tool life, severe damage and delamination to CFRP layers and clogging of drill flutes. These difficulties can be attributed to the poor machinability of the stacked constituents and the differences in properties across the thickness of the stacks. Similarly, studies done on drilling Fiber Metal Laminates (FML) consisting of stacks of Glass Fiber Reinforced Polymer (GFRP) and Aluminium sheets have reported drilling-induced damages and delamination. There have been reports of machining hybrid composite metal stacks using non-traditional machining processes such as Abrasive Waterjet Machining (AWJM), Rotary Ultrasonic Machining (RUM), and Electrical Discharge Machining (EDM). Studies on

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drilling of CFRP/Ti stacks through RUM process suggested longer tool life and better surface quality in RUM compared to conventional drilling. Studies on both AWJM process and EDM process reported limitations in machining hybrid composite stacks. While AWJM causes delamination of FRP layers, EDM process produces extremely low surface finish along with cracks in the matrix material.

Keywords: Carbon Fiber Reinforced Polymer, Finite Element Analysis, Micro Ultrasonic Machining