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Investigation on the performance of SiAlON ceramic drills on aerospace grade CFRP composites

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ABSTRACT

Carbon fiber reinforced polymer (CFRP) composites are widely used in aircraft structure due to their outstanding physical and mechanical properties. Drilling is one of the most critical operation in the handling of CFRP composites, since the delamination free holes with high dimensional accuracy are required for assembly. The quality of the machined holes strongly depends on machining conditions, tool geometry and tool wear. There are a limited number of tool materials which can survive in the abrasive cutting conditions formed by the fractured carbon fibers during drilling. SiAlONs are promising materials for the machining of CFRP composites due to their superior abrasive wear resistance. SiAlON ceramics have been reported for the first time in the literature as cutting tool materials for drilling of CFRP composites in this study, where α/β-SiAlON drilling tools with four different sets of common drill geometries were manufactured and tested extensively on drilling of aerospace grade CFRP composites. The effects of cutting parameters and geometrical features of novel α/β-SiAlON drilling tools on the cutting forces and the peel-up delamination of the machined holes were investigated. It was observed that the point angle and chisel edge length of the novel SiAlON drilling tools are the main parameters that affect the maximum thrust force and delamination during drilling. The thrust force exhibited an increase during drilling tests, indicating that an abrasive wear occurs at the cutting edges of the SiAlON drilling tools.

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1. Introduction

Nowadays, carbon fiber reinforced polymer (CFRP) composites are highly critical and commonly used materials with rapidly increasing trend in various industries such as aerospace, automotive and marine industries due to their high strength to weight ratio and mechanical and chemical durability. The optimum combination of these properties mainly depends on the properties and the structure of the carbon fibers which are oriented in the composite panel. Although CFRP composites are generally produced in near net shape, holes for the assembly of the panels need to be manufactured with a high dimensional accuracy and surface quality. Drilling plays a very important role in the assembly of the CFRP composite panels. Müller-Hummel et al. (2008) reported that more than 55,000 holes are generally required to be drilled as in a complete single unit production of the Airbus A350 aircraft. Drilling is one of the most critical processes in order to obtain holes with tight tolerances and the best possible quality due to the highest safety requirements in the aerospace industry.

Since the composite laminates show a high tendency to delamination when subjected to mechanical stresses in the drilling axis, it is necessary to minimize the thrust force exerted by the drill bit in order to obtain damage free holes. Indentation effect caused by the quasi-stationary drill chisel edge was reported by Durao et al. (2010) as the main mechanism responsible for the delamination. This effect can be reduced by the correct choice of cutting parameters (feed and cutting speed (f, v)), drill geometry (chisel edge, point angle, rake angle, helix angle, etc.) and the drill material (coated and uncoated carbides, PCD tools, etc.). Khashaba et al. (2010) investigated the effect of cutting conditions and drill diameters on thrust force, delamination and surface roughness of the machined holes in woven glass fiber-reinforced epoxy composites. Their results indicated that there is a linear relationship between thrust force and feedrate due to increased resistance to chip formation with increasing feedrate. Karpat et al. (2012) also observed this linear relationship in the drilling of CFRP composites with carbide and diamond coated carbide drills with two double point angle.

The geometric features of a standard drill bit used in FRP composite drilling such as point angle, chisel edge length, helix angle,

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rake and clearance angle, etc. are considered as the tool variables that are effective on the quality of the machined holes. It was proposed by Wang and Zhang (2008) that a modification of the rake face of a standard twist drill via wheel grinding can reduce the thrust force and torque by as much as 46.9% and 24.9%, respectively. Extension of the drill life was also achieved by this modification. Piquet et al. (2000) investigated the influence of drill geometry on the delamination of CFRP composites. They proposed to increase the number of cutting edges and to reduce the contact length between the tool and the composite material in order to reduce delamination. Ho-Cheng and Tsao (2006) compared different drilling tools with special geometries. According to theoretical predictions and experimental results, they concluded that the core drill, candle stick drill, saw drill and step drill can be operated at larger feedrates without delamination in comparison to a standard twist drill since the trust force exerted by these special drills are distributed toward the drill periphery rather than to be concentrated at the hole center reducing the delamination. Abrao et al. (2007) and Durao et al. (2010) examined the influence of drill geometry on thrust force and delamination formed during drilling of Fiber Reinforced Composites (FRP). In contrast to the previous observations by Chen (1997) and Ho-Cheng and Tsao (2006), these authors concluded that the delamination does not only depend on the thrust force, but also the geometrical details of the drilling tools.

Apart from tool geometry and cutting conditions, hole quality is also affected by the tool wear which leads to an increase in the thrust force. Koplev et al. (1983) expressed that unlikely to chip formation mechanism in metal machining, the material is removed by brittle fracture of the carbon fibers from a FRP composite, giving rise to formation of abrasive powder-like chips. These chips cause a severe abrasion at the cutting edge of the tool. Besides abrasion, micro-chipping can also be observed as a dominant wear mechanism due to high cyclic loads caused by the fiber orientation in the CFRP composite. Consequently, rapid tool wear becomes unavoidable. There are a limited number of wear resistant materials successfully used for machining of FRP composites such as polycrystalline diamonds (PCD) and diamond coated carbides. Relatively high cost is the main drawback of these materials, even if they provide longer tool life (5–10 times higher) than uncoated carbide counterparts. Therefore, there is always a strong demand for new cutting tool materials with an outstanding wear resistance and reasonable cost in the machining industry. α/β-SiAlON composites are used in many structural applications, where both low and high temperature wear resistance is required, such as turning operation of heat resistant alloys at which the temperature can exceed 1000 °C. Due to their outstanding mechanical, thermal and chemical properties, SiAlONs are good candidates for machining of FRP composites. However, SiAlON ceramics have not been reported in the literature as cutting tool materials for drilling of CFRP composites so far. In this study, it was aimed to investigate and compare the performance of SiAlON tools with different geometries in terms of drilling forces and hole quality, and to determine a convenient geometry for these novel drilling tools for further wear analyses.

2. Experimental procedure

2.1. Preparation of SiAlON rods for the manufacturing of drilling tools

Si_3N_4 (UBE-SE10), AlN, Al_2O_3, Y_2O_3, Sm_2O_3 and CaO (in the form of $CaCO_3$) were used in the starting batch which was subsequently charged into an attrition mill. The mixture with 60 wt.% of solid loading was attrition milled for 2 h in an aqueous medium to reduce particle size and obtain homogeneity. A mixture of organics (polyethylene glycol as a plasticizer, acrylic emulsion as a binder and a wax based lubricant) was added to the SiAlON slurry for further powder consolidation. The slurry was then spray-dried in order to obtain nearly spherical-shaped granules with an average granule size of ~100 μm and high flowability. Cold isostatic press was utilized to compact the granules into cylindrical rod shape at 200 MPa in a flexible polyurethane die. The diameter and the length of SiAlON rods are 10 mm and 80 mm, respectively. After shaping, organic additives in compacts were removed by a heat treatment process at 650 °C with a dwell time of 1 h in air. Following the heat treatment, the SiAlON rods were sintered at a maximum temperature of 1950 °C for 1 h under 100 bar N_2 gas pressure in a gas pressure sintering furnace.

2.2. Manufacturing of SiAlON drilling tools

Sintered SiAlON rods were ground into 4 different geometries by a CNC grinding center (Makino/GF8) and the diamond wheels (Wendt-D45 grit) attached to the machine. The pictures and the geometrical details of the drills after grinding are given in Figs. 1 and 2, respectively. Helix angle (β) of all the drilling tools was kept constant at 20°. G-1 is a patented geometry at which the point

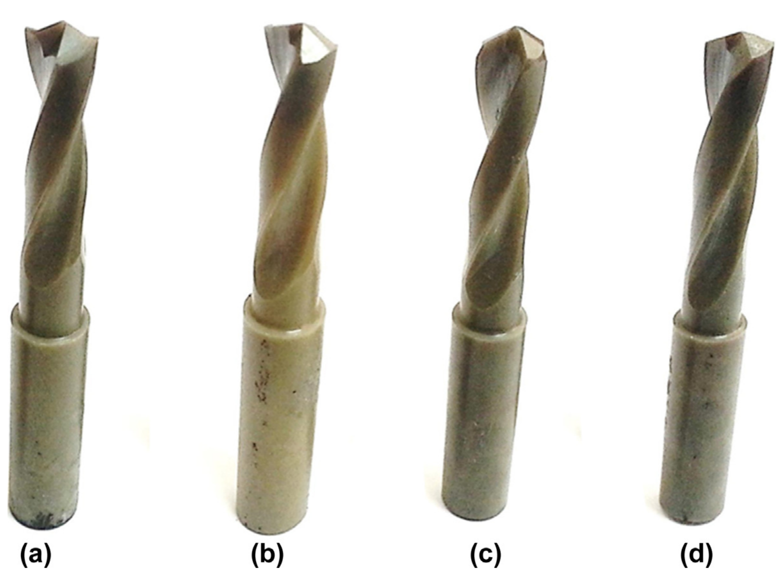

Fig. 1. SiAlON drilling tools (a) G-1, (b) G-2, (c) G-3 and (d) G-4 (Ø = 6.4 mm).

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