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Influence of cooling on the performance of the drilling process of glass fibre reinforced epoxy composites

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ABSTRACT

Non-laminated composites find application in construction of bridges, ballistic applications, etc. However, literature on the drilling of non-laminated composite materials and literature on the drilling of thick composite materials under different cooling methods (dry, external and internal) is scarce. Hence the present study is aimed to investigate the influence of different cooling methods on quality characteristics (drill temperature and damage factor) while drilling glass fibre reinforced epoxy (GFRE) non-laminated 20 mm thick pultruded composite rods having 80% fibre weight fraction and 0° fibre orientations with respect to the drill. The drilling experiments using TiN/TiAlN coated tungsten carbide twist drills of diameter 10 mm were conducted using response surface methodology (RSM). The experimental values obtained for quality characteristics are empirically related to process parameters by developing a response surface model using Design-Expert software. The effects of process parameters on quality characteristics were analysed by using response surface graphs. The process parameters (feed, spindle speed and coolant pressure) are also optimized within the selected range. The optimal parameter levels are confirmed by validation test. From this investigation, it is evident that the internal cooling method is significant for obtaining high hole quality.

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1. Introduction

Glass fibre reinforced epoxy (GFRE) composites are most widely used in aerospace, automotive, marine, oil, gas and process industries, construction of military vehicles, machine tools, robots and sports equipment owing to their multi-potential properties such as high strength-to-weight ratio, high specific stiffness, high damping, and high fracture toughness [1,2]. Accordingly, the need for accurate machining of GFRE composites has increased enormously. Intricacy in the product design necessitates development of the composite product in parts, which are finally assembled. Hole making thus becomes an essential part in product development.

Drilling of GFRE composites leads to the generation of different kinds of defects such as delamination, fibre breakage and matrix cracking [3,4]. Among these defects caused by drilling, delamination which occurs both at the entrance and exit planes of the workpiece is the most critical, since it can result in lowering of bearing strength and thereby reduces service life of the component [3,5,6]. Also, as composites are poor conductors of heat, the drill temperature affects tool wear and thereby hole quality. Hence, utmost care is to be exercised to attain defect controlled drilling performance. The fastening efficiency is largely dependent on the bearing strength which defines the quality of machined holes. Many researchers have proposed that the quality of machined holes is strongly dependent on process parameters such as feed and spindle speed [2,3,7–10]. Therefore, it is essential to optimize the drilling process parameter levels to attain high hole quality.

Many attempts have been made by various researchers in dry drilling of thin laminated glass fibre reinforced composites. They are briefly presented here. Dorr et al. [11] have studied temperature during the drilling process, including the effect of different tool coatings. Bono and Ni [12,13] have studied the temperature distribution along the cutting edges of a drill and investigated the influence of emerging heat on hole diameter and cylindricity of dry drilled holes. They also subsequently developed a model for predicting the heat flow into the workpiece in dry drilling [14]. Agapiou and DeVries [15,16] have analytically calculated the temperature distribution on the flank face and cutting edges of twist drill to study the thermal phenomena during the cutting process and compared the same with experimental results. Komanduri and Hou [17], Tay [18], Da Silva and Wallbank [19] reviewed the methods to measure temperature between cutting tool and workpiece as well as cutting tool and the chip. Chen [20] and Fuh et al. [21] have developed a 3D finite element module to compute the temperature distribution at the first cutting edge of drill tool as well as the flank face. In their study, the effects of cutting depth, cutting speed, web thickness and helix angle on the temperature changes were investigated. Singh and Bhatnagar [22] studied the drill induced damage of uni-directional GFRP composite laminates. Velayudham and Krishnamurthy [23] studied the effect of point geometry and its influence on the delamination of polymeric composites.

Caprino et al. [4] found that feed rate significantly influences the damage induced in glass/polyester composites while drilling. Chen [24] correlated the delamination factor with the average thrust force for the drilling of uni-directional (UD) and multi-directional composite materials. Takeyama and Lijima [25] studied the surface roughness on ultrasonic machining of glass fibre reinforced plastic (GFRP) composites. According to them, higher cutting speed produces more damage on the machined surface. This is because of higher cutting temperature, which results in local softening of work material. Khashaba et al. [26] studied the effect of feed, drill diameter and cutting speed on thrust force, delamination size and surface roughness while drilling GFRE composites. They found that the increase in the feed results in higher thrust force which in turn increases the resulting surface roughness and delamination damage and subsequently low bearing strength.

The literature review shows that many researchers have worked towards attaining hole quality considering thrust force, torque, surface roughness, drill temperature and damage/delamination around the dry drilled hole in thin laminated composites. However, literature on the drilling of non-laminated composite materials and literature on the drilling of thick composite materials under different cooling methods (dry, external and internal) is scarce. Non-laminated composites, because of their superior properties than laminated composites, find application in construction of bridges, prefabricated walkways and platforms, bus components, ballistic applications, etc. In ballistic applications, mostly thick non-laminated composites with a higher percentage of fibre weight fractions are used to ensure higher order energy absorption.

Hence the present study is aimed to investigate the influence of different cooling methods (dry, external and internal) on quality characteristics (drill temperature and damage factor) while drilling GFRE non-laminated thick pultruded composites having 0° fibre orientations with respect to the drill. Since pultruded composites with 0° fibre orientations are extensively used in structural engineering applications, fishing rods, electrical insulator rods and many other innovative new products, it has been taken for machinability study. The process parameters (feed, spindle speed and coolant pressure) are optimized within the selected range for minimizing the quality characteristics together using response surface methodology (RSM). The paper also presents the application of RSM to attain response surface model for quality characteristics with significant process parameter terms by analysing signal/noise (S/N) ratio. If drill temperature and drill induced damage can be minimized, the bearing strength of the drilled holes and thereby the service life of the assembled components can be substantially increased.

2. Experimental details

Pultruded solid round rod of a GFRE non-laminated composite with a high fibre weight fraction was selected as the workpiece. Pultruded rod of 20 mm length and 25 mm diameter was made using epoxy (Araldite LY 556, manufactured by HUNTSMAN, India) as resin, Aradur HY 951 (manufactured by HUNTSMAN, India) as hardener, Talc (EX-MX-20P, manufactured by Golcha,