ARCHIVES OF CIVIL AND MECHANICAL ENGINEERING 16 (2016) 565–575

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: http://www.elsevier.com/locate/acme

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

B. Ramesh [a,b,*], A. Elayaperumal [a], S. Satishkumar [c], Anish Kumar [d], T. Jayakumar [d], D. Dinakaran [e]

[a] Department of Mechanical Engineering, College of Engineering Guindy, Anna University, Chennai 600 025, India
[b] Department of Mechanical Engineering, St. Joseph's Institute of Technology, Chennai 600 119, India
[c] Department of Mechanical Engineering, Velammal Engineering College, Chennai 600 066, India
[d] Metallurgy and Materials Group, Indira Gandhi Centre for Atomic Research, Kalpakkam 603 102, India
[e] Department of Mechanical Engineering, Hindustan University, Padur, Chennai 603 103, India

ARTICLE INFO

Keywords:
GFRE
Non-laminate
Drill temperature
Ultrasonic C-scan imaging
Damage factor

ABSTRACT

Non-laminate composites find their paramountcy in large structures, ballistic applications, etc. However, literature about the hole making process in thick composites, non-laminate composites and that under different cooling methods (dry, external and internal) is scarce. Hence the present study examines how the different methods of cooling influence the quality characteristics (drill flank temperature and damage factor) during drilling 20 mm thick Glass Fibre Reinforced Epoxy (GFRE) pultruded composite rods having 80% fibre weight fraction and 0° fibre orientations with reverence to the feed direction. Response Surface Methodology (RSM) was used to design the drilling experiments and the latter was executed utilizing 10 mm diameter twist drills made of cemented carbide. Response surface models utilizing Design-Expert software were developed, which empirically relates the process parameters with the obtained experimental values of quality characteristics. The effects caused by process parameters on quality characteristics were analyzed by utilizing response surface graphs. The process parameters (spindle speed, feed per revolution and coolant pressure) have been optimized within the selected range. The optimal parameter levels are attested by validation test. The contribution of this investigation is to make understand that the use of twist drill with internal cooling is critical to get damage tolerance holes.

DOIs of original articles: http://dx.doi.org/10.1016/j.acme.2015.03.001, http://dx.doi.org/10.1016/j.acme.2016.02.003

[*] *Corresponding author at*: Department of Mechanical Engineering, College of Engineering Guindy, Anna University, Chennai 600 025, India. Tel.: +91 9840106249.

E-mail address: rameshphd2010@yahoo.in (B. Ramesh).

http://dx.doi.org/10.1016/j.acme.2016.02.002

1. Introduction

Malhotra [1] and Arul et al. [2] have stated that the glass/epoxy composite materials are widely employed in many industries and applications because of the desirable properties they have. Because of the intricacies in the design, composite products are developed in elements. Consequently, the demand for perfect hole making in Glass Fibre Reinforced Epoxy (GFRE) composite materials has exaggerated tremendously. Thus hole making for the fabrication of elements has become an all-important voice in the development of composite products.

Different sorts of damage, for example, breakage of fibres, delamination, cracking of resin [3,4] results while making holes in glass/epoxy composite materials. Out of the damages caused by the process of drilling, delamination occurring at the entryway and the exit of the hole is critical, as it brings down the efficient lifetime of the product by decrementing the bearing strength of the fastener holes [3,5,6]. Besides, as composites are poor conductors of heat, the drill flank temperature affects hole quality by influencing tool wear. Hence, ultimate care should be given to attain damage constrained drilling. The quality of drilled holes is restrained by the bearing strength that determines the fastening potency. Several researchers [2,3,7–10] urged that the bearing strength of holes strongly depends on drilling parameters namely spindle speed and feed per revolution. Thus, it becomes indispensable to arrive optimum drilling parameter levels for attaining high hole quality in glass/epoxy composites.

Various efforts are established by several researchers in the hole making process with fibre glass reinforced thin composite laminates. The following is the brief review of the literature. Dorr et al. [11] have investigated the drill temperature based on infrared radiation, letting in the outcome of different coatings of the tool. Bono and Ni [12] predicted the effects of thermal distortion of the drill and work material on the cylindricity and diameter of the holes during dry drilling. Further, they [13] developed a drill-foil thermocouple system to measure the temperature distribution along the cutting edges. They [14] also subsequently developed a finite element model for estimating the temperature field and the flow of heat into the work material for a range of speeds and feeds and verified through dry drilling experiments. Agapiou and DeVries [15] proposed an analytical method to estimate the steady and transient state temperature distributions along the twist drill cutting edge and on the flank (clearance) face and also examined the analytical results using a drilling process. They [16] also found that the mean flank temperature of the drill predicted from the steady state model is very close to the experimental value whereas that from the transient model overestimates the experimental value. Komanduri and Hou [17] reviewed various experimental techniques to quantify heat and temperature produced in drilling, turning and grinding and also in tribological applications. They also reviewed the above techniques with its merits and demerits. Tay [18] reviewed various methods to quantify the temperature developed during steady state machining. He also discussed the main assumptions and boundary conditions practiced in various methods. Da Silva and Wallbank [19] attempted to review analytical and experimental strategies used to quantify cutting temperature. Chen [20] numerically quantified the distribution of temperature along the primary (straight and curved) cutting edges and on the flank faces utilizing the variational approach of the three-dimensional finite element method. He found that thick web drill (3.6 mm) with curved primary cutting edges performs better, less flank wear, than straight primary cutting edges due to better uniform distribution of temperature and a comparatively lower temperature along the primary cutting edges and on the flank faces. He also found that the temperature is maximized on the flank face at some distance from the periphery of drill. Fuh et al. [21] investigated the effects of the depth of penetration, the cutting speed, the helix angle and the thickness of the web on the steady and transient state temperature distribution by using a three-dimensional finite element method and thereby provided the optimum working condition of a high-speed steel twist drill. Singh and Bhatnagar [22] examined the effect of cutting speed/feed speed ratio on thrust force, torque and damage while drilling glass/epoxy composite laminates using solid carbide drills of diameter 4, 6 and 8 mm with different drill point geometries namely jodrill, 8-facet, 4-facet and parabolic point.

Velayudham and Krishnamurthy [23] experimented to understand the effect of drill point geometry on thrust and exit delamination while drilling glass/phenolic-woven fabric composites consisting of 63% of fibre volume fraction and of 7 mm thick. Caprino et al. [4] concluded that high feed rate produces damages similar to impact damage, whereas low feed rate produces typical push-out delamination while making holes in glass/polyester composite laminates using standard high-speed steel drill tool. Wen-Chou Chen [24] proposed a new concept called delamination factor to assess the degree of drilling induced delamination in composite laminates. He further demonstrated that delamination-free drilling is possible with proper selection of drill geometry and feed rate. Takeyama and Lijima [25] evaluated the chip formation, cutting force and surface finish besides proposing a new methodology to evaluate the mean cutting force with respect to the orientation of fibres with cutting direction. They constitute that ultrasonic machining of fibre reinforced plastics is superior in terms of surface finish. The experimental work carried out by Khashaba et al. [26] in glass/epoxy composite laminates demands the reduction of thrust force to improve the bearing strength of the drilled holes. They constitute that delamination damage is proportional to feed and diameter of drill and inversely proportional to bearing strength, whereas surface roughness is proportional to feed rate.

From the above review of literature one can understand that many works have been made for procuring good quality holes in thin composite laminates by giving due consideration of machinability characteristics. Up to now, literature regarding the hole making process in thick composites, non-laminate composites and under different methods of cooling (dry, external and internal) is sparse. Non-laminate composites find more significance than laminate composites in structural applications, attributable to their enhanced mechanical properties. Bodies subjected to motion demand materials that can absorb higher energy and for such applications non-laminate thick composites comprising a maximum weight fraction of fibre can be habituated to guarantee best performance.