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Experimental investigations on drilling of lignocellulosic fiber reinforced composite laminates

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ABSTRACT

Natural or lignocellulosic fibre reinforced composites have a plethora of salient characteristics such as low density, fairly good mechanical properties; consume low energy during processing and non-toxic to the environment. Due to these properties, lignocellulosic fibre reinforced composites have many applications in the engineering field. Drilling is an inevitable machining operation because it facilitates the assembly of different parts of a structure. This paper presents the drilling performance of lignocellulosic fibre reinforced polymer composites. The experimental investigation was carried out using 4-facet, 8-facet, dagger, step and parabolic drill bits at a different combination of feed and speed of the drill bit. The drilling performance was evaluated in terms of drilling forces, delamination and surface roughness of the machined hole. Additionally, the influence of the drilling temperature on the force and damage has been experimentally investigated.

1. Introduction

Lignocellulosic fibre reinforced composites are used in numerous practices ranging from construction, aviation, and automobile industries due to their diversified advantages such as low-carbon footprint, low-cost, non-abrasive nature and adequate thermal, electrical and mechanical properties [1]. These biodegradable materials are highly competitive and are extensively used as an alternative to the conventional non-biodegradable composites. Lignocellulosic fibre based composite products are fabricated close to the final shape during the primary manufacturing process, thus, reduces the need for the secondary manufacturing process. But the manufacturing of intricate product requires consolidation of several parts together by means of mechanical fastening which can be achieved by making hole and then installing the fasteners. Therefore, drilling was recognized as an essential machining operation to meet the integrity of the final product [2]. But drilling behaviour of lignocellulosic fibre reinforced composites does exhibit different behaviour in several ways from that of metals and alloys because of their anisotropy and heterogeneous nature [3]. Moreover, drilling causes damage of the hole in terms of chipping, delamination, spalling, fibre pull-out etc. The main reasons for such damages are high drilling forces and temperature. The poor interfacial bonding strength between hydrophobic polymer and hydrophilic lignocellulosic fibre also affects the mechanical and machining performance of these composites [4]. Lignocellulosic fibre reinforced composites also limit their application spectrum to low-temperature engineering practices as they have the tendency to degrade at low temperature (≈200 °C). Also, lignocellulosic fibre reinforced composites have poor thermal conductivity as compared to the conventional metals and alloys, and hence, they could not ably dissipate the heat generated during machining [5]. These comply that the drilling behaviour of lignocellulosic fibre reinforced composites is quite complex and need a better understanding of the process mechanism to produce superior quality holes. A handful of investigations have been reported pertaining to the area of drilling behaviour of lignocellulosic fibre reinforced composites. Bajpai et al. [6] investigated the hole making performance of sisal/polypropylene composites using different drill bits at various feed and speed of the drill bit. Innovative tool point geometry was conceptualized and developed which showed that the developed cutting tool can significantly reduce the damage of the drilled hole as compared to the twist drill bit in nettle/epoxy and sisal/epoxy laminates [7]. The drilling investigation on nettle/polypropylene composite has been carried out [8]. The results inferred that parabolic drill bit coupled with low feed and high spindle speed reduces the induced drilling forces. Bajpai et al. [9] statistically established the fact that drill geometry is the vital parameter that influences both forces and damage produced during making of holes in grewia optiva/PLA and sisal/PLA laminates. The drilling behaviour of unidirectional sisal/epoxy and sisal/polypropylene composites were studied [10]. The authors suggested that the drilling performance of these composites depend not

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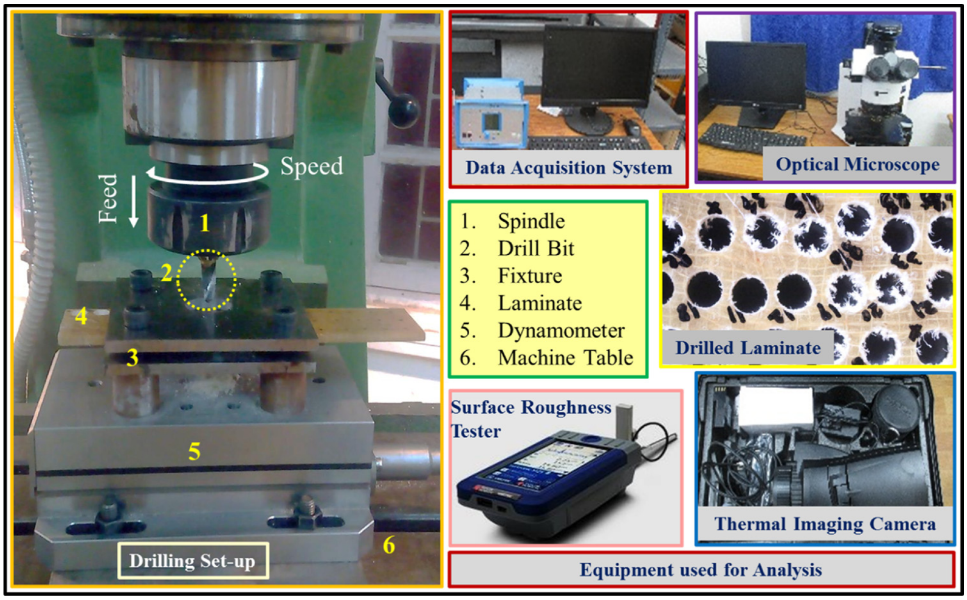

Fig. 1. Drilling set-up and the eqipment used to anlyse the drilled hole.

only on the type of polymer reinforced with the fibres but also on the geometry of the drill bit and cutting parameters. Jayabal et al. [11] explored the performance of hole making in coir/polyester composites. It was established that the performance of a drill bit of 6 mm diameter is noteworthy as it generates minimum forces and tool wear as compared to the higher drill bit diameters. Athijayamani et al. [12] recommended that the chemical treatment of natural fibres improves the machinability of hybrid composites. It was also reported that the fibre content of 30% and the alkali treatment enhances the dimensional accuracy of the drilled hole. The drilling performance of other type of lignocellulosic fibre reinforced composites such as flax/polypropylene composites [13]; glass/coir/polyester hybrid composites [14]; coir/polyester composites [15,16]; basalt/sisal composites [17]; sisal/glass/vinyl ester hybrid composites [18]; hemp/polyester, jute/polyester, banana/polyester and glass/polyester composites [19]; bamboo/polyester composites [20]; roselle/sisal/polyester hybrid composite [21]; and banana/epoxy composites [22] have also been investigated. Yashiro et al. [23] stated that drilling temperature also significantly affects the integrity of the drilled hole. Therefore, the analysis of both force and temperature induced during drilling are important as these parameters exert an influence on the life span of the drill bit and quality of the hole. Weinert and Kempmann [24]; Pinho et al. [25]; Ramesh et al. [26]; Li et al. [27]; and Merino et al. [28] have focused their investigation on drilling temperature and its influence on the quality of the hole produced in synthetic fibre composites. The investigation on the analysis of temperature during drilling of lignocellulosic fibre reinforced composites is rarely reported in the literature. Hence, in this experimental endeavour, an emphasis is given to investigate the temperature that generates during drilling of lignocellulosic fibre reinforced composites along with the induced drilling forces, delamination and surface roughness of the hole.

2. Material and methods

2.1. Fabrication of composites

Nettle fibres in woven form were used as reinforcement for fabricating the laminate. Nettle fibres are often used in aircraft panels due to their excellent breaking tenacity and flexibility properties [29,30]. Fibre-yielding plant, Himalayan nettle *(girardinia diversifolia)* is abundantly cultivated in the Indian Himalayan Region (IHR). Hand lay-up technique was applied to reinforce the commercially available epoxy resin (LY 556 and HY 951) into the woven fabric nettle fibre mats. Initially, the hydrophilic nettle fibres were pre-heated in an oven at 80 °C for 6 h to remove the absorbed moisture. A total of 4 layers of woven fabric mats were used to manufacture a laminate of 4 mm thickness. These 4 layers of fibre mats contribute a weight fraction of 55% of the total weight of laminates. The epoxy resin is reinforced into mats of fibre using nip-roller-type impregnators. After impregnation of resin into the fibre mats, the complete system is kept under the standard atmospheric condition to cure the epoxy resin. The laminates are then cut into required dimensions.

2.2. Measurements

The drilling performance of the laminates was investigated under dry condition using knee-type vertical milling machine (Make: Batliboi Ltd., Model: BFV5). The prepared composite specimen was mounted on a fixture that was clamped on a dynamometer. The dynamometer can measure the force to a range of -5–$+100$ kN in the Z direction with a sensitivity of -3, 7 pC/N. The natural frequency of the dynamometer is approximately 3, 5 kHz. The dynamometer was attached to the multi-channel charge amplifier (Make: Kistler, Type: 5070 A) and data acquisition card (Make: Kistler, Type 5697A1). The force signals were captured using data acquisition software (Dynoware, Version: 2.3: 5.16, Type: 2825-A-02) that is installed in the personal computer. A very high sampling rate is considered and set to 1000 Hz so that the minor variation in the signals can be detected. The holes were produced at different levels of feed (8, 16 and 22.4 mm/min) and spindle speed (710, 1400 and 2000 RPM) using 4-facet, 8-facet, step, parabolic and dagger drill bits. All the drill bits were of the same diameter (8 mm) and made of solid carbide. The whole experimental set-up and drill bits under investigation are shown in Figs. 1 and 2, respectively. Table 1 represents the important dimensions of the drill bits under investigation.

The drilling temperature was measured using infrared camera and software. Thermographic camera (Make: Testo, Model: 885-2 SET) was used to measure the in-situ temperature that generates at the top ply of the laminate during the drilling operation. The recorded thermographs were further analysed using Data Capture Program (1394) (TH71-717, Version: 2.0 C) to calculate the temperature of the hotspot. The infrared camera features an infrared resolution of 320×240 pixels, thermal sensitivity of < 30 mK at $+30$ °C, and the accuracy of ± 2 °C. The