Chapter 11
Modeling and Optimization of Abrasive Water Jet Cutting of Kevlar Fiber–Reinforced Polymer Composites

Tauseef Uddin Siddiqui
M.J.P. Rohilkhand University, India

Mukul Shukla
University of Johannesburg, South Africa and
Motilal Nehru National Institute of Technology (MNNIT), India

ABSTRACT

This chapter presents a detailed study of abrasive water jet (AWJ) cutting of thin and thick Kevlar fiber-reinforced polymer (FRP) composites used in transport aircraft and anti-ballistic applications. Kevlar composites are considered to be very challenging to machine using traditional techniques. Most of the research conducted in the area of AWJ cutting has been limited to single response optimization. However, in real life machining, the performance of a process/product demands multi-objective optimization (MOO). No work has been reported till now using different MOO techniques for AWJ cutting of Kevlar FRP composites. Experimental modeling of depth of cut and various design of experiments based single and multi-objective optimization studies are presented here. Statistical analysis of variance has been performed to rank the different process parameters and estimate their effects on various AWJ cut kerf quality characteristics. The studies conducted in this chapter are likely to prove beneficial to the AWJ community in performing modeling and simultaneous optimization of multiple quality characteristics.

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1. INTRODUCTION

1.1 Kevlar Fiber-Reinforced Polymer Composites

Kevlar fiber-reinforced polymers (KFRP) are high tensile strength and tensile modulus composite materials especially desirable for their outstanding strength to weight ratios, which is even superior to metals. They are known for their toughness, impact resistance, resistance to creep and fatigue failure. Typical KFRP applications include ballistic products (bulletproof vests, military tanks, helmets), tires, ropes, missile cases, and as a replacement in automotive brake and clutch linings and gaskets. Machining of FRP composites is different in many aspects from machining of metals due to their anisotropy and in-homogenous nature. The machining of FRP composites generates several kinds of damage like fibre pullout, delamination and poor surface quality which severely affect their mechanical performance (Davim et al., 2004).

Glass and Carbon based FRPs can be machined easily with standard tools. However, the higher toughness of aramid fibers creates a problem during machining and special tooling and techniques are required (Bhattacharyya and Horrigon, 1998; Azmir et al., 2009). The extensive usage of Kevlar in high performance anti-ballistic applications has given rise to a need for an efficient method of machining Kevlar composites.

1.2 Abrasive Water jet Machining

Abrasive water jet machining (AWJM) is a non-traditional machining method that offers a productive alternative to conventional techniques. Material removal occurs through erosion and results from the interaction between an abrasive water jet and the work-piece materials (Palleda, 2007). The basics of AWJM are reviewed in detail by (Momber and Kovacevic, 1998). AWJM is considered to be promising machining tool for difficult-to-machine materials (Patel, 2004). In contrast to this, it is quite complex in view of several process parameters such as hydraulic, abrasive, mixing and cutting parameters influencing the performance of the process. Generally, the process performance can be evaluated in terms of depth of cut, material removal rate, cutting efficiency, kerf geometry and cut surface topography (Jegaraj and Babu, 2005). The cut geometry depends on the type of abrasives and cutting parameters like abrasive jet pressure, standoff distance (SOD) of the nozzle from the target, work feed rate, abrasive mass flow rate, etc (Khan and Haque, 2007).

This advanced machining technology allows difficult-to-cut materials such as ceramics, metal alloys, and composites to be machined efficiently at reasonable speeds (Hashish, 1989; Arola and Ramulu, 1994; Wang, 1999; Chen and Siores, 2003, Jegaraj, 2007; Zhang et al., 2009, Liu, H.T, 2010, Kong et al., 2011). AWJ can virtually cut any material without any significant heat damage or distortion. Because the cutting forces are very small and no cutting tools are required, the setup time is shorter than traditional machining processes and fixturing requirements are either minimal or non-existent. Depending on the capabilities of the CNC machine, it is possible to cut two-dimensional contours and even complex three-dimensional shapes with AWJ. AWJ produces no airborne dust, does not use chemicals, exposes no heat or fumes to the atmosphere and all the debris is carried away by the high-pressure water slurry into the catcher. A typical Omax® AWJM setup is shown in Figure 1.

The basic objective of the present chapter is to generate an experimental and numerical understanding of the effect of different process parameters on various kerf quality characteristics (KQCs) like surface roughness, top and bottom kerf widths and kerf taper, to get a superior cut surface quality. The popularly used Taguchi method (TM) of design of experiments (DOE) has been used for optimization of experimentation and process performance. This approach leads to a study of possible interaction between the process