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ORIGINAL ARTICLE

An optimization technique on ultrasonic and cutting parameters for drilling and deep drilling of nickel-based high-strength Inconel 738LC superalloy with deeper and higher hole quality

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Abstract In this research work, an ultrasonic assisted drilling system is employed to apply both rotation and vibration to drill bits. The transducer horn transfers power very efficiently and changes tools effortlessly. The setup used to conduct drilling tests is Inconel 738LC with depth-to-diameter ratios from 2 to 10 by conventional drilling (CD), ultrasonic assisted drilling (UAD), and electro discharge drilling (EDD). The effects of ultrasonic vibration amplitude, spindle speed, and number of steps to drill each hole on machining force and surface roughness in UAD are investigated. The results demonstrate not only a significant improvement in tool life (by applying ultrasonic vibration to the drilling process) but also a 40 % reduction in thrust force compared to CD. The UAD technique seems more appropriate than the EDD method due to the ability to reduce machining process time by up to 90 %, improve cylindricity by roughly 50 %, increase hole dimension accuracy by up to 80 %, and reduce surface roughness by 52 %.

Keywords Ultrasonic assisted drilling · Superalloy · Inconel 738LC · Drilling thrust force · Quality of hole

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1 Introduction

Superalloys are extensively used in advanced industrial areas, such as power stations and aerospace. These materials display superior properties including very high hardness and stiffness maintainable at medium temperatures (750 °C for Inconel 738LC), high wear resistance, as well as high corrosion resistance. Inconel 738LC is used in turbine blades in gas and steam power stations. The principal difficulty with utilizing these materials is their low machinability. One of the most time-consuming processes in manufacturing superalloy blades is drilling, as conventional drilling is nearly unattainable and must be done via electro discharge machining (EDM). EDM has the advantage that no direct contact occurs between the tool and workpiece. All conductive materials can be drilled with EDM, but processing time is much longer and surface quality lower than mechanical drilling. The ultrasonic assisted drilling (UAD) technique is a modern system that renders the feasibility of mechanically drilling superalloys. In this technique, high-frequency vibrations between 16 and 40 kHz and amplitudes of 2 to 30 μm in the direction of the drill axis are applied. The use of ultrasonic vibration dates back to over 50 years ago [1]. One of the earliest studies on ultrasonic vibration in drilling was performed by Takemaya et al. [1] who investigated the effects of ultrasonic vibration on decreasing burr size. Research works have since been conducted with UAD on various materials such as bone [2, 3], aluminum [1, 4–7], steel and its alloys [8–10], particle-reinforced metal matrix composites (PRMMCs) [11, 12], copper [13], titanium alloy [14, 15], and nickel-based superalloys [16, 17].

Azarhoushang and Akbari [16] utilized UAD to make holes in Inconel 738LC. They added vibration to the drill bit and rotation to the workpiece; however, they did not investigate drilling force. It was demonstrated that ultrasonic vibration can decrease surface roughness, improve dimensional

accuracy, and make the impossible task of conventionally drilling such superalloy a feasible process. Nevertheless, applying rotation to the workpiece restricts the setup operation to few small workpieces. The researchers drilled 8-mm-deep and 5-mm-diameter holes, while in many applications, the required depth of cut is ten times or more that diameter—which is why it is called deep drilling. On the other hand, different results may be obtained if both rotation and vibration are applied to the drill bit, which is an essential requirement if the process is to be introduced to industrial units.

The electro discharge drilling (EDD) method is normally used for making holes in turbine blades of Inconel 738 LC superalloy. This method is time-consuming, and the quality of the holes is not adequate. This study is thus conducted with the goal of making the mechanical drilling of this superalloy possible. Mechanical deep drilling is studied using conventional and ultrasonic assisted methods to obtain holes with 50-mm overall depth and 5-mm diameter. The efficiency of ultrasonic assisted drilling is compared with EDD and electro discharge deep drilling (EDDD) tests in terms of surface roughness, dimensional accuracy, and processing time. In order to achieve optimal mechanical drilling results, surface roughness and thrust force are measured and analyzed in all experiments. To verify the predicted optimum conditions, ultrasonic assisted deep drilling (UADD) tests are conducted in optimum condition.

2 Experimental details

2.1 Experimental setup

A schematic of the ultrasonic assisted drilling experimental procedure is illustrated in Fig. 1. To facilitate the experiment, a container was designed and fabricated such that the transducer can be held within and clamped to the chuck of the lathe

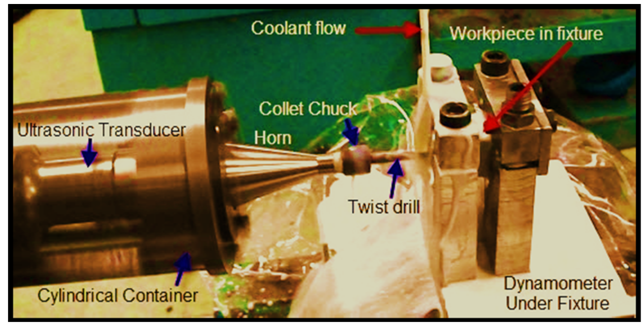

Fig. 2 Experimental setup

(see Fig. 2). Electrical power was fed through a slip ring to the transducer inside the cylindrical container. The horn was held by the container in its vibration node and transferred rotation and vibration to the drill bit. Modal analysis was conducted, and the horn was designed via finite element method. The horn worked in its resonance frequency 20.3 kHz. Three amplitude levels were selected for the UAD and UADD tests: 3, 6, and 10 μm. The ultrasonic generator was controlled with LabVIEW software. During the drilling process, the dynamometer beneath the fixture recorded force signals. The signals were magnified by an amplifier and sent to a computer. The force results were then displayed as a graph of force in DynoWare software (Figs. 1 and 2). A universal lathe machine (Tabriz-TN40A) was employed for turning the ultrasonic head in conventional and ultrasonic assisted drilling as well as deep drilling tests. A spark erosion machine (EDM-404ZMC, EKRAMCO) was utilized to perform EDD and EDDD drilling. A super drill machine (YGS-43Z, YOUGAR) with kerosene as dielectric fluid made overall holes of ϕ2 mm in the 50-mm-long workpieces in order to achieve better results in EDDD (make a fluid path). A Mastersonic MMM generator—MSG.1200.IX—converted 50-Hz electrical supply to high-frequency electrical impulses. The generator's frequency range was 19 to 46 kHz, the frequency step was 1 Hz, the power was 1,200 W, and the maximum output current was

Fig. 1 Experimental procedure