ABSTRACT

The superior properties in terms of high strength, corrosion resistance, heat resistance, fatigue resistance and low thermal conductivity of Inconel 718 alloy leading to wider applications in aircraft, automotive, energy, marine, medical and petrochemical industries. However work hardening during machining, presence of high abrasive particles particularly at high temperatures, ability to weld and form built-up edge, high toughness, low thermal conductivity resulting in excessive tool wear or shorter tool life during conventional machining. Hence, this material is considered as ‘difficult to machine’ material. To overcome these shortcomings, innovative hybrid machining processes are being developed over the last decades. Laser assisted hybrid machining (LAHM) is one of the hybrid machining methods which combines the process of heating and material removal simultaneously.

In this work, the experimental investigations are carried out to systematically study the benefits of LAHM of Inconel 718 alloy using TiAlN coated carbide inserts. The process parameters considered are laser approach angle, laser power, cutting speed and feed rate. The experimental work is carried out in three phases. In first phase the laser preheating experiments are carried out based on central composite design of $L_{31}$ array in response surface methodology to determine the optimum range of parameters for the desired surface temperature and heat affected depth. The experimental parameters selected are cutting speed in the range of 50-100 m/min, feed rate of 0.05-0.1 mm/rev, laser power of 1250 W–1750 W and approach angle of 60°–90°of laser beam axis to the cutting tool. Parametric significance is analysed using analysis of variance (ANOVA) and 3D surface plots. The structural changes of the material surface were observed using optical microscope and quantitative measurement of affected depth were analysed by vicker’s hardness test. From the laser screening test results it is determined that the optimum laser beam angle of 60° produces the effective heat affected depth of 0.5 mm.
In second phase, the machining experiments are carried out under LAHM based on full factorial experimental design to determine the effect of process parameters such as cutting speed, feed rate and laser power on the responses, cutting force, surface roughness and flank wear. Laser approach angle of 60° is kept throughout the experiments in order to maintain effective heat affected depth. The parametric effects are analysed using main effect plot, analysis of variance and surface plots. Then input – output relationship model for LAHM process is developed using response surface methodology (RSM) and artificial neural network (ANN) modeling approaches in order to predict the results accurately. From the results, it is determined that the ANN model estimates the responses with high accuracy compared to the response surface model.

Compared to conventional machining (CM), the LAHM results the following reduction benefits: i) 46% in feed force (Fx), 36% in thrust force (Fy) and 34% in cutting force (Fz), ii) improved surface finish (Ra) 50% and iii) improvement in tool wear by 68%. The chip morphology reveals that the saw-tooth chip with a maximum un-deformed chip thickness of about 170 μm in LAHM is responsible for the amplitude of reduction benefits. The shear angle in chip formation is reduced and chip thickness increased which resulting increased chip segmentation during LAHM of Inconel 718 compared to conventional machining.

In third phase, the optimum level of LAHM parameters is determined using desirability function approach for single and multi-response criteria. Under the optimum conditions, the tool life and surface integrity analysis is carried out and the results are compared with conventional machining. It is found that PVD coated carbide tool provides 133% increase in tool life with the dominant mode of tool failure to be flank wear.