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An experimental analysis and measurement of process performances in machining of nimonic C-263 super alloy

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ABSTRACT

Nimonic C-263 alloy is extensively used in the fields of aerospace, gas turbine blades, power generators and heat exchangers because of its unique properties. However, the machining of this alloy is difficult due to low thermal conductivity and work hardening characteristics. This paper presents the experimental investigation and analysis of the machining parameters while turning the nimonic C-263 alloy, using whisker reinforced ceramic inserts. The experiments were designed using Taguchi's experimental design. The parameters considered for the experiments are cutting speed, feed rate and depth of cut. Process performance indicators, viz., the cutting force, tool wear and surface finish were measured. An empirical model has been created for predicting the cutting force, flank wear and surface roughness through response surface methodology (RSM). The desirability function approach has been used for multi response optimization. The influence of the different parameters and their interactions on the cutting force, flank wear and surface roughness are also studied in detail and presented in this study. Based on the cutting force, flank wear and surface roughness, optimized machining conditions were observed in the region of 210 m/min cutting speed and 0.05 mm/rev feed rate and 0.50 mm depth of cut. The results were confirmed by conducting further confirmation tests.

1. Introduction

Nickel based super alloys are finding wider applications in the development of critical components, for high-performance aircraft gas turbine engines, due to their superior mechanical properties that are maintained at elevated temperatures. Aerospace components continually suffer from extremes of temperature, pressure and velocity, and are often in service for many decades. It is also critical that the most stringent quality controls are in place, when the parts are machined. Reliability is an important criterion in the manufacture of aerospace components, and therefore, these component manufacturers need to maintain high-quality on a consistent basis. The exacting standards of aerospace machining make it mandatory, that each part be machined with absolute precision, no matter how challenging the task. At the same time, rising material prices are making the cost of scrap higher than ever, making minimization of waste more important than ever. As the super alloys are quite costly and considered as difficult-to-machine materials, the parts are to be manufactured with utmost care without any rejection, and keeping the requisite quality characteristics in view. Above all, the risk of failure by fracture or fatigue necessitates that components fabricated from the super alloys are of the highest integrity, so that inspection and lifetime estimation procedures are critical to safe ongoing operations. Among the functional characteristics, surface roughness is still one of the most important parameters, used to evaluate the surface integrity of the machined components, because it directly controls surface functions such as friction, wear, lubricant retention and load carrying capacity. It also significantly influences fatigue strength, corrosion resistance, and creep

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life which are prerequisites in the case of aerospace components [1]. To control the surface characteristics, it is necessary that the cutting parameters have to be optimized for the work and tool material combinations. Therefore, the main focus of this paper is to conduct a metal cutting study, and optimize the machining parameters in terms of the surface quality characteristic (roughness), tool wear and cutting force, while turning the nimonic C-263 alloy.

Following the pioneering work of Taylor [2] and his famous tool life equation, different analytical and experimental approaches for the optimization of machining parameters have been investigated. Despite Taylor's early work on establishing the optimum cutting speeds in single pass turnings, progress had been slow, since all the process parameters need to be optimized. Furthermore, for realistic solutions, several constraints, such as low machine tool power, torque, and force limits component surface roughness, need to be overcome in practice. Singh and Kumar [3–5] have applied Taguchi's technique for optimizing the surface finish, tool wear, cutting force and power consumed in turning operations for machining En24 steel with titanium carbide-coated tungsten carbide inserts. Asilturk and Akkus [6] were used Taguchi technique to determine the effect of cutting parameters on surface roughness in hard turning of AISI 4140 steel.

Tool wear rate is highly dependent on the cutting conditions, tool geometry, material hardness, etc. The flank wear rate is increased when the cutting speed is increased; for a constant feed rate and depth of cut also, the flank wear rate gradually increases, when the cutting speed and cutting time increases on turning the Inconel 718 [7]. Pawade et al. [8] investigated the effect of the machining parameters and cutting tool edge geometry on surface integrity, during the turning of the Inconel 718 alloy, by conducting experiments based on Taguchi's method L_{27} orthogonal array. The significant machining parameters and their interaction effects were identified with the help of the ANOVA. Ezugwu and Okeke [9] have studied the performance of titanium nitride coated carbide inserts, during the machining of the nickel based C-263 alloy at high speed conditions. The study indicated that the feed rate was the dominant factor affecting the tool performance in terms of tool life. Reduction in tool life was also observed with an increase in the depth of cut. An increase in the cutting speed and depth of cut resulted in accelerated flank wear and a proportional increase of the components forces. Ezugwu and Okeke [10] have investigated the performance of multilayer TiN/TiC/TiN and TiAlN PVD coated carbide tools, in terms of tool life, surface finish and cutting forces during the machining of the nimonic C-263 alloy. The study indicated that the multilayer coated carbide insert gave a longer tool life than the single layer coated carbide insert.

The RSM, as employed in the investigation, is a collection of mathematical and statistical techniques, that is useful for the modeling and analysis of problems, in which a response of interest is influenced by several variables and the objective is to optimize the response [11]. The ANOVA is used for checking the validity of the developed model and to study the effect of machining parameters on responses [12]. In order to obtain good surface quality and dimensional properties, optimized cutting conditions have to be employed, which also need a suitable modeling technique for better prediction. From the above, it is seen that optimization is one of the important activities for the economy of manufacture, and to predict the performance characteristics of machining [13–15]. Therefore, in the present work the optimization of the machining parameters, such as the cutting speed, feed rate, and depth of cut, based on the response factors, viz, the cutting force, flank wear and surface roughness, is made. Taguchi's L_{27} array was used for conducting the experiments. The study also aims to develop a model, with the help of the response surface methodology approach for predicting the cutting force, flank wear and surface roughness during the machining of the nimonic C-263 alloy, with a whisker reinforced ceramic insert. The multiple performance optimization of the machining parameters is carried out, using the response surface methodology, based on the desirability function approach.

2. Experimental details

2.1. Work material and cutting tool

The nimonic C-263 alloy material of 80 mm diameter and 300 mm length was used for all the experiments. The chemical analysis has been carried out using the spark emission spectrometer. The chemical composition of the work piece material is as follows (wt%): 52.49 Ni, 0.19 Si, 0.46 Mn, 20 Cr, 6.29 Mo, 0.07 Cu, 1.0 Fe, 16.7 Co, 1.94 Ti, 0.48 Al, 0.04 Nb, 0.15 W, 0.02 V, 0.02 C, 0.001 S, 0.007 Ta. The work material was solution treated to a hardness of 32HRc.The experimental study was carried out on a NAGMATI175 lathe, which has the following specifications: height of centers 165 mm, swing over bed 305 mm, spindle speed range 54–1200 rpm, feed range 0.048–0.716 mm/rev and main motor power 1HP. Because nickel based (super alloys) materials are metallurgically composed to have high strength at high temperatures, the stresses that are generated when machining, are high. The unique capability of these super alloys to perform close to the melting point of their basic metal, gives poor machinability due to their low thermal conductivity. In the hard condition, after aging, the heat generated during cutting is so high that only grades with the highest hot hardness are practical. Furthermore, the surface is prone to work hardening, which means that notch wear is a critical issue. Therefore, suitable tool materials should be selected for machining nickel based alloys.

Of the tool materials, fined grained PVD coated 'S' grade cemented carbide and whisker or Sialon grade ceramics are suitable for machining nickel based alloys. Compared to carbide, the ceramic cutting tool possesses higher hot hardness and thus can retain its cutting wedge (form stability) for a longer time, and can also operate at a higher cutting speed. This will also facilitate better surface finish. Therefore, in this study, Sandvik make whisker reinforced ceramic insert to the specification of CNGN 12 04 08T01020 670, was chosen as the tool material for conducting turning trials. Correspondingly, a turning tool