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ORIGINAL ARTICLE

An optimization method of the machining parameters in high-speed machining of stainless steel using coated carbide tool for best surface finish

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Abstract High-speed machining (HSM) has emerged as a key technology in rapid tooling and manufacturing applications. Compared with traditional machining, the cutting speed, feed rate has been great progress, and the cutting mechanism is not the same. HSM with coated carbide cutting tools used in high-speed, high temperature situations and cutting more efficient and provided a lower surface roughness. However, the demand for high quality focuses extensive attention to the analysis and prediction of surface roughness and cutting force as the level of surface roughness and the cutting force partially determine the quality of the cutting process. This paper presents an optimization method of the machining parameters in high-speed machining of stainless steel using coated carbide tool to achieve minimum cutting forces and better surface roughness. Taguchi optimization method is the most effective method to optimize the machining parameters, in which a response variable can be identified. The standard orthogonal array of L_9 (3^4) was employed in this research work and the results were analyzed for the optimization process using signal to noise (S/N) ratio response analysis and Pareto analysis of variance (ANOVA) to identify the most significant parameters affecting the cutting forces and surface roughness. For such application, several machining parameters are considered to be significantly affecting cutting forces and surface roughness. These parameters include the lubrication modes, feed rate, cutting speed, and depth of cut. Finally, conformation tests were carried out to investigate the improvement of the optimization. The result showed a reduction of 25.5% in the cutting forces and 41.3% improvement on the surface roughness performance.

Keywords Taguchi · Optimization · High speed · Machining · Lubricant · Cutting · Force · Roughness

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1 Introduction

High-speed machining (HSM) is gaining popularity in industry in recent years due to the capability in improving machining performance, reducing cost while achieving reduced lead times, and higher productivity [1]. However, the demand for high quality focuses attention on the surface condition and the quality of the product, especially the roughness of the machined surface because of its effect on product appearance, function, and reliability. In addition, a good quality machined surface significantly improves fatigue strength, corrosion resistance, and creep life. Besides that, the quality of the machined surface is useful in diagnosing the stability of the machining process, where a deteriorating surface finish may indicate workpiece material non-homogeneity, progressive tool wear, cutting tool chatter, etc. For these reasons, it is important to maintain consistent tolerances and surface roughness. Surface roughness is defined as a group of irregular waves in the surface, measured in micrometers (μm). The roughness data obtained by measurement can be manipu-

lated to determine the roughness parameter. There are many different roughness parameters in use, but R_a is by far the most common. Other common parameters include R_z, R_q, and R_{sk}.

Surface roughness is mainly affected by different machining parameters that can be setup in advance, such as rotation speed, feed rate, and cut depth. However, it is also affected by other uncontrol variables such as the mechanical properties of the material, the type of the cutter, and the vibration produced during the process. The cutting speed and feed rate are significant machining parameters affecting surface roughness; however, the effect of depth of cut is small [2–8]. The use of higher cutting speed and lower feed rate produced a better surface finish and this is mainly attributed to the high temperature [8, 9]. However, with higher cutting speed and temperature, special rapid tooling is needed to increase abrasion resistance and hence produced good surface roughness. For rapid tooling applications in the die and mold industry, it will lead to great improvements if tool can be used for machining with shorter lead times and better surface finish. The achievement of these objectives by HSM puts it at the priority of rapid tooling and manufacturing technologies. Whereas, tool life is important for cost purposes, the surface finish is consider a direct measure of the quality of product produced. Coating tools are traditionally expected to play multiple roles such as reducing cutting temperatures and cutting forces and increasing abrasion resistance [10, 11]. It is clear that the coated cutting tool provided a lower surface roughness; however, the benefits will depend on many factors, including substrate material, tool coating combinations, and the thermophysical conditions of both tool and workpiece. The application of coated carbide tools has been found to bring about an expansion of the region of machining conditions within which reduced wear rates may be experienced [7]. The effect of tool coatings is thus expected to be the broadening of the lowest wear zone on the feed-cutting speed wear map. In addition, coatings are expected to result in lower wear regions occurring at higher spindle speeds, promoting the use of HSM.

Although, coating tools are playing a key role to reduce the cutting temperatures, it is however still high as the friction between cutting tool and workpiece is also high due to extensive contact during machining. The cutting temperature is a key factor, which directly affects cutting tool wear, workpiece surface integrity, and machining precision according to the relative motion between the tool and work piece [12]. The amount of heat generated varies with the type of material being machined and machining parameters especially cutting speed, which had the most influence on the temperature [13]. Several attempts have been made to predict the temperatures involved in the process as a function of many parameters. Da Silva and Wallbank [14] presented a review for cutting temperature prediction and measurement methods. Additionally, many experimental methods to measure temperature directly, only a few systems have as yet been used this temperature as an indicator for machine performance monitoring and for industrial application. Therefore, design and develop control system to control the temperature lead to better surface finish, as machine performance parameter is required [14]. Thus, the implementation of cutting fluid, which acts as a lubricant and a coolant, are very crucial. However, the usage of conventional flooding application in machining processes is becoming debatable because machine operators could be exposed to possible health problems [9, 15]. In addition, the bulk of waste from the conventional flooding technique might be disposed off irresponsibly thus causing serious damage to the environment. Economically, the cost related to the cutting fluid is 7–17% of total production cost which is normally higher than that of cutting tool equipments which incurs only 2–4% of total cost [11].

An alternative has been suggested in which a high pressure jet of soluble oil was applied directly to the chip-tool interface. This has been reported to reduce cutting temperature and improve tool life due to its ability to penetrate into the chip–tool interface [9]. Klocke and Eisennblatter [16] state that minimal quantity lubrication (MQL) refers to the use of cutting fluids of only a minute amount—typically of a flow rate of 50–500 ml/h which is about three to four orders of magnitude lower than the amount commonly used in flood cooling condition. In addition, it is also reported that MQL increases the machining processes efficiency by improving its overall performance compared to dry and conventional flood machining [3, 9, 17, 18]. Besides that, study on machining austenitic stainless steels indicated that high-pressure MQL give better performance in drilling and turning [19]. However, the investigations of milling process with MQL especially in high-speed milling of austenitic stainless steels are still at an early stage and many areas of research is yet to be explored. This is because of the high ductility of stainless steel that categorizes it to be amongst the difficult to cut materials [2, 20, 21].

Following the review above, this study included lubrication mode, feed rate, spindle speed, and dept of cut as machining parameters (called control factor hear after) affecting the surface roughness. The main objective is to find the best combination of theses parameters in high-speed machining of stainless steel using coated carbide tool to achieve low cutting force and surface roughness. The conventional method to achieve that is to use the “trial and error” approach. However, due to the large number of experiments, the “trial and error” approach is very time consuming. Hence, a reliable systematic approach for optimizing the machining parameters is thus required.