journal homepage: www.elsevier.com/locate/jmatprotec

A grey and fuzzy algorithms integrated approach to the optimization of turning Hadfield steel with Al_2O_3/TiC mixed ceramic tool

*Jenn-Tsong Horng, Ko-Ta Chiang**

Department of Mechanical Engineering, HsiuPing Institute of Technology, No. 11, Gungye Road, Dali City, Taichung 41280, Taiwan, ROC

ARTICLE INFO

Article history:
Received 19 September 2006
Received in revised form
9 October 2007
Accepted 14 December 2007

Keywords:
Grey relational analysis
Fuzzy
Optimization
Hadfield steel
Ceramic tool

ABSTRACT

This paper focuses on the development of a fast and effective algorithm to determine the optimum manufacturing conditions for turning Hadfield steel with Al_2O_3/TiC mixed ceramic tool by coupling the grey relational analysis with the fuzzy logic. The flank wear and surface roughness were adopted to evaluate the machiniablity performances. Various cutting parameters, such as cutting speed, feed rate, depth of cut and nose radius of tool were explored by experiment. An orthogonal array was employed for the experimental design. This proposed algorithm obtains a grey–fuzzy reasoning grade to evaluate the multiple performance characteristics through the grey relational coefficient of each performance characteristic. The response table, response graph and analysis of variance (ANOVA) were used to find the optimal levels and the effect of cutting parameters on the flank wear and surface roughness. A confirmation test within the optimal machining parameters was conducted to indicate the effectiveness of this proposed algorithm. Experimental results have shown that the required performance characteristics in the turning process have great improvements through this proposed algorithm.

1. Introduction

Among metal cutting techniques the turning is one of the important and widely used manufacturing processes in engineering industry. With regard to the quality characteristics of turning produces parts, some of the problems include surface roughness, burr and tool wear. Cutting speed, feed rate, depth of cut, features of tools, work piece material and coolant conditions are the cutting parameters which highly affect the performance characteristics. It is necessary to select the most appropriate machining settings in order to improve cutting efficiency, process at low cost and produce high-quality products. The optimization techniques of cutting parameters through experimental methods and mathematical and statistical modes have grown substantially over time to achieve a common goal of improving higher machining process efficiency.

The austenitic Hadfield steel containing about 1.0–1.2 mass% C and 11–14 mass% Mn (Hadfield, 1925) has a variety of wear-resistance application such as drivable parts of railway, rolling parts of steel-making factory and wear-resistance parts of machining equipments. The various mechanical characteristics of Hadfield steel have been already performed and the details of experimental investigations are extensively explained (Cahn, 1977; Bayraktar and Altintas, 1996; Canadinc et al., 2005; Gavriljuk et al., 2006). Because of

* Tel.: +886 4 24961108; fax: +886 4 24961108.
E-mail addresses: horng@mail.hit.edu.tw, horngjt@hotmail.com (J.-T. Horng), kota@mail.hit.edu.tw, vgear2001@yahoo.com.tw (K.-T. Chiang).
0924-0136/$ – see front matter
doi:10.1016/j.jmatprotec.2007.12.060

the strain hardening behavior of Hadfield steel including high hardness and huge machining hardenability, it is difficult cutting material. Hence, large cutting force, high cutting temperature and wear of cutting tool are easy happened so that it is difficult to control the precision of dimensions in the machining process. Therefore, it is important duty to acquire the machinablity evaluation in turning process. Especially, for machining various hardened materials, the choices of cutting tool and appropriate cutting parameters have become an important topic about increasing the productivity and reducing the power consumption.

Ceramic tools are widely used for machining of various hardened materials in the manufacturing industry. The characteristics of ceramic possess high melting point, excellent hardness and good wear resistance (Dewes and Aspinwall, 1997). Alumina (Al_2O_3)-based ceramics are frequently used to be one of the most suitable tool material for machining hardened materials. Obikawa et al. (1997) investigated the crater wear characteristics of alumina coated and alumina ceramic tools by analyzing the stress and temperature on the rake face. Xu et al. (2001) performed an investigation of mechanical property and cutting performance of yttrium-reinforced Al_2O_3/Ti(C,N) composite ceramic tool material. Barry and Bryne (2001a,b) studied the mechanism of Al_2O_3/TiC and cubic boron nitride (CBN) cutting tool wear in the machining of hardened steels. From the above researches, the results show that the adequately additions of TiC, Ti(C,N), ZrO_2, TiB_2 improve the mechanical property of the ceramic tool material. It is also proposed that the mechanical property of ceramic tool wear are dependent on the tool geometry and cutting parameters including cutting speed, feed rate and depth of cut.

The main objective of present study is to employ the grey relational analysis and fuzzy logic to establish an integrated algorithm in order to determine the optimal settings of cutting parameters with considerations of performance characteristics during the turning Hadfield steel with Al_2O_3/TiC mixed ceramic tool. The grey relational analysis theory, initialized by Deng (1989) and Deng (1982), makes use of grey relational generating and calculates the grey relational coefficient to handle the uncertain systematic problem under the status of only partial known information. The grey relational coefficient can express the relationship between the desired and actual experimental results, and the grey relational grade is simultaneously computed to each machining response. The single grey relational grade can provide an optimal setting of cutting parameters in which manufacturing simultaneously requests multiple performance characteristics (Lin and Lin, 2002; Narender et al., 2004). In addition, the theory of fuzzy logic which was originated by Zadeh (1965) is an effective mathematical module of resolving problem which contains huge uncertain information. The fuzzy logic analysis including the max–min fuzzy inference and centroid defuzzification method (Zimmermann, 1985) adopts the fuzziness of human concepts to deal with multiple performance characteristics. Therefore, the fuzzy logic can also be applied to establish the optimal setting of cutting parameters with considerations of multiple performance characteristics. In this study, the optimal settings through this integrated algorithm which combines the grey relational analysis with fuzzy logic will be verified with the experimental results for turning Hadfield steel with Al_2O_3/TiC mixed ceramic tool. This proposed algorithm utilized in this study will reveal the improvement of required performance characteristics in the turning process.

2. The integrated algorithm of grey relational analysis and fuzzy logic

2.1. Grey relational analysis

The grey represents the primitive data having poor, incomplete and uncertain information, and the incomplete relationship of information among these data is called the grey relation. Grey relational analysis uses the quantitative analysis to describe the degree of relationship between an objective sequence (a collection of measurements or experimental results) and a reference sequence (target value) in the grey system. The measurement of relationship between two above sequences can be expressed as the grey relational coefficient. In the grey system, the set of sequence X_i is expressed as follows:

$$X_i = [X_i(1), X_i(2), \ldots, X_i(k)], \quad i \in I, \ \ k \in N \tag{1}$$

where $X_i(k)$, $i \neq 0$ is the objective sequence and $X_0(k)$ is the reference sequence. In the procedure of grey relational analysis, the raw sequences are first normalized in the range between 0 and 1 due to the different measurement units and scales, which process is called the grey relational generating. The normalized results reveal the situation of better performance in the grey relational analysis. The large value of normalized results can express the better performance, and the best-normalized results will be equal to one. The normalized type depends upon the characteristics of raw sequence including the larger-the-better, smaller-the-better and nominal-the-better characteristic. Consequently the type of normalized results can be expressed as following for the larger-the-better characteristic:

$$X_i^*(k) = \frac{X_i(k) - \min\limits_{\forall k} X_i(k)}{\max\limits_{\forall k} X_i(k) - \min\limits_{\forall k} X_i(k)} \tag{2}$$

for the smaller-the-better characteristic:

$$X_i^*(k) = \frac{\max\limits_{\forall k} X_i(k) - X_i(k)}{\max\limits_{\forall k} X_i(k) - \min\limits_{\forall k} X_i(k)} \tag{3}$$

and for the nominal-the-better characteristic:

$$X_i^*(k) = 1 - \frac{\left| X_i(k) - X_{ob}(k) \right|}{\max\limits_{\forall k} X_i(k) - \min\limits_{\forall k} X_i(k)} \tag{4}$$

where $\max\limits_{\forall k} X_i(k)$ and $\min\limits_{\forall k} X_i(k)$ is the largest and smallest value of $X_i(k)$, respectively and $X_{ob}(k)$ is the target of $X_i(k)$. The grey relational coefficient $\xi_i(k)$ for $X_i(k)$ to $X_0(k)$ is calculated as follows:

$$\xi_i(k) = \frac{\Delta \min + \beta \Delta \max}{\Delta_{0,i}(k) + \beta \Delta \max} \tag{5}$$