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# Optimization of Fractal Dimension of Turned AISI 1040 Steel Surface Considering Different Cutting Conditions:
## Fractal Dimension of Turned Steel Surface

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### ABSTRACT

The present work examines the effect of turning process parameters, namely depth of cut and feed rate on the fractal dimension of AISI 1040 steel. Machined surfaces have been characterized using fractal dimensions. Apart from the aforesaid conventional turning parameters, cutting condition has been also considered as a design variable. Three cutting conditions have been considered, e.g. dry, water lubricated, and commercially available water-soluble emulsion lubricated condition. The depth of cut and feed rate has been also been varied at three levels. Experiments were performed following Taguchi's $L_9$ orthogonal array. The optimal setting of process parameters has been achieved through the use of Taguchi's quality loss function represented by a signal-to-noise ratio. The optimal condition predicted from Taguchi's analysis is a 0.4 mm depth of cut, a 0.07 mm/rev feed rate and a water-based emulsion cutting environment. The results obtained for fractal dimensions has been also compared with the more conventional roughness parameter centre line average roughness which is dependent on instrument resolution.

### KEYWORDS

AISI 1040 Steel, ANOVA, Fractal Dimension, Surface Roughness

### INTRODUCTION

The challenge in modern industry is to manufacture low cost, high quality products in terms of work piece dimensional accuracy, surface finish, high production rate, less wear on the cutting tools and also in short time period with less environmental impact. Machining plays an important role in manufacturing products. Machining by turning in general involves the process of material removal from the outer surface of cylindrical or conical components. Turning is one of the most fundamental and most widely used material removal processes in a real manufacturing environment amongst

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various cutting processes (Zerti et al., 2019). The quality of manufactured products is determined by its surface quality or surface roughness which is produced due to mechanism of the material removal process. Surface roughness is characteristic evidence on a machined surface in the form of finely spaced micro irregularities left by the cutting tool (Davim, 2008).

Surface roughness in general is characterized by amplitude, spacing and hybrid parameters (Sahoo, 2005). Amplitude parameters include center line average roughness (Ra), root mean square roughness (Rq), etc. Spacing parameters are characterized by mean line peak spacing (Rsm), high spot count, etc. Hybrid parameters include root mean square wavelength of profile, root mean square slope, etc. The effect of turning process parameters on surface roughness has been investigated extensively through the use of design of experiments (DOE) and statistical techniques (Haque et al., 2017). The most widely used optimization technique over the years has been the Taguchi coupled grey relational analysis (GRA) and response surface methodology (RSM) due to their simplicity, cost-effectivity and quick outcomes (Zerti et al., 2018; Lin, 2004; Bouacha et al., 2010; Nian et al., 1999; Asiltürk & Neşeli, 2012; Yang & Tarng, 1998; Nalbant et al., 2007; Saidi et al., 2019; Alok & Das, 2019). Asiltürk & Neşeli (2012) investigated the effect of influence of cutting speed, feed rate and depth of cut on surface roughness of AISI 304 austentitic stainless steel using Taguchi based RSM. Optimal Ra was achieved for 50 m/min cutting speed, 0.15 mm/rev feed rate and 1.5 mm depth of cut. Yang and Tarng (1998) investigated the effect of cutting speed, feed rate and depth of cut on Ra of S45C steel bars using Taguchi's signal to noise (S/N) ratio and analysis of variance (ANOVA). Optimal Ra was achieved at 135 m/min cutting speed, 0.08 mm/rev feed rate and 1.1 mm depth of cut and feed rate was seen to have the highest contribution in controlling the Ra. The OA, Taguchi analysis and ANOVA was used to predict optimal parametric condition to achieve minimum surface roughness of AISI 1030 steel in turning (Nalbant et al., 2007). An insert (TiN coated) radius of 1.2 mm, feed rate of 0.15 mm/rev and depth of cut 0.5 mm results in improved Ra. ANOVA results indicated that insert radius and feed rate were the most influential parameters. Likewise Taguchi based GRA, RSM and ANOVA was used study the effect of turning parameters on roughness of different grades of steel, metal matrix composites, brass, copper, titanium alloy (Ti-6Al-4V), etc. (Lin, 2004; Bouacha et al., 2010; Saidi et al., 2019; Alok & Das, 2019; Palanikumar & Karthikeyan, 2006; Li & Laghari, 2019; Sahoo et al., 2008; Liang et al., 2019).

Apart from GRA or Taguchi's quality loss function, genetic algorithm (GA) has been successfully coupled with RSM to obtain optimal parametric setting for minimizing Ra of AISI 1040 steel (Sahoo, 2011). The predicted optimal roughness (Ra = 0.864 μm) using GA was obtained for 0.261 mm depth of cut, 1864 rpm spindle speed and 0.127 mm/rev feed rate (Sahoo, 2011). In a recent study, the Ra of EN-GJL-250 cast iron while turning was studied by Laouissi et al. (2019) and optimization of process parameters was carried out using GA. On the other hand, Raja & Baskar (2011); they demonstrated the use of particle swarm optimization for minimizing surface roughness of different materials such as aluminium, copper and brass. To enable design engineers take quick decisions on problems and system capabilities, artificial intelligence (AI) techniques such as fuzzy logic, artificial neural networks (ANN), adaptive neuro fuzzy inference (ANFIS), etc., has shown excellent modeling capabilities (Mukhopadhyay et al., 2019). A back propagation neural network was used to predict the relationship between turning process parameters such as speed, feed and depth of cut with Ra and a good correlation between predicted and experimental results were observed for mild steel (Pal & Chakraborty, 2005). Davim et al. (2008) also demonstrated the use of ANN for modeling surface roughness of free machining steel with process parameters such as feed rate, cutting speed and depth of cut with fairly high correlation coefficient of 0.95. On the other hand, Abburi & Dixit (2006) formed a fuzzy knowledge base based on if – then rules. A combination of fuzzy knowledge base trained using ANN is known as ANFIS and has even better surface roughness prediction capabilities and capture any degree of non-linearity (Roy, 2013).

Cutting fluids play a crucial role in improving machining efficiency, tool life and surface integrity. Though, there are associated health and environmental concerns with the use of cutting fluids. Water