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Analytical Models for Tool Wear Prediction during AISI 1045 Turning Operations

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Abstract

Tool wear is one of the most important topic in cutting field. Its interest is due to the influence of tool wear on surface integrity of the final parts and on tool life, and, consequently, on the substitution policies and production costs. Analytical models, able to forecast the tool wear with a satisfactory accuracy, can give to the companies working in the material removal field a valid instrument to optimize the cutting processes. In the present work a comparison between response surface methodology (RSM) and artificial neural networks (ANNs) fitting techniques for tool wear forecasting was performed. For developing these predictive models, tool life tests, consisting of longitudinal turning operations of AISI 1045 steel bars using uncoated tungsten carbide inserts and variable cutting parameters, were conducted. Both flank (VB) and crater wears (KT) of the tool were monitored. The models were validated comparing the calculated tool wear values with the experimental ones, showing that ANNs model provides better approximation than RSM in the prediction of the amount of the tool wear parameters. So, from an industrial point of view, this model should be implemented into a production management software in order to correctly define the tool substitution policy during batch production.

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Keywords: tool wear; analytical model; Response Surface Methods; Artificial Neural Networks.

1. Introduction

In manufacturing field, turning operation is a very common material removal technique. Researches on this topic take into account several aspects, such as: geometrical and metallurgical characteristics of the cutting tool, workpiece material influence on the process and process parameters (cutting speed, feed rate, depth of cut). The interaction of all these factors during a cutting operation causes a series of physical, chemical and thermo-mechanical phenomena that influence the wear of the tool. In cutting operations it is difficult to establish a dominant cause [1] of tool wear. In fact, a simultaneous combination of several and different wear mechanisms like abrasion, adhesion, diffusion or oxidation, can be observed. The ISO 3685 standard describes how tool wear can be measured providing a description of the parameters to control during tool life tests.

Typically, flank wear (VB) and K ratio (ratio between depth of the crater wear – KT – and the position of the maximum depth of crater – KM), are the most used ones because of their influence on tool life, substitution policy, manufacturing costs and surface integrity of the final part in terms of surface roughness [2], residual stress distribution [3-5] and strain hardening [6].

For these reasons, a good way to optimize a turning process is the possibility of predicting the tool wear. Since the on-line evaluation of the tool wear parameters during a turning process is a very expensive and time consuming effort for industries, it is very important to provide models able to predict these parameters with a good accuracy. For this purpose response surface methodology (RSM) [7,8] or artificial neural networks (ANNs) [9] can be utilized. The RSM technique fits data

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coming from experimental tests with a suitable analytical function applying statistical rules and regression modeling techniques. While ANNs are global optimization algorithms employed in solving difficult problems.

The aim of the present research is to apply RSM and ANNs techniques in order to obtain models able to predict flank wear (VB) and crater depth (KT) when turning AISI 1045 steel bars with uncoated tungsten carbide (WC) tools. Experimental tests provided the tool wear data, needed for developing the models. Longitudinal turning operations were carried out and the development of flank wear (VB) and depth of crater wear (KT) was measured. The considered variables are the cutting time and the main process parameter (i.e., cutting speed and feed rate). Design of experiments (DOE) technique was utilized for planning the experimental campaign.

For evaluating the influence of the selected variables on the tool wear, a preliminary ANOVA analysis was performed on the data collected during the experimental campaign. After that, the RSM analysis was carried out, defining a second order analytical model for VB and KT prediction.

ANN's, based on backpropagation and feed-forward algorithm, were tested too. The wear models validation was performed using tool wear data collected performing additional experimental tests using cutting conditions different from those used during the training and the validating phases.

The models are able to forecast VB and KT with a good accuracy. The best performances were obtained when using ANNs technique.

2. Experimental campaign

The experimental campaign was performed on a CNC lathe. Longitudinal turning operations on cylindrical bars made of AISI 1045 steel, with an initial diameter of 98 mm and a length of 275 mm, were realized. Tungsten carbide ISO P40 inserts (ISO specification SPUN 120308) with a nose radius of 0.8 mm and a flank angle (α) equal to 11° was utilized during the tests. Even if the ISO P40 inserts quality is not the best choice for cutting AISI 1045 steel, this insert material quality was chosen for obtaining high wear rate. The selected toolholder (ISO specification CSBPR 2020K12) is characterized by:

- rake angle (γ) equal to +1°;
- inclination angle (λ) equal to +7°;
- entering angle (χ) equal to 75°

Figure 1 shows the experimental set-up, while Table 1 summarizes the chemical composition and the mechanical characteristics of tool and workpiece materials.

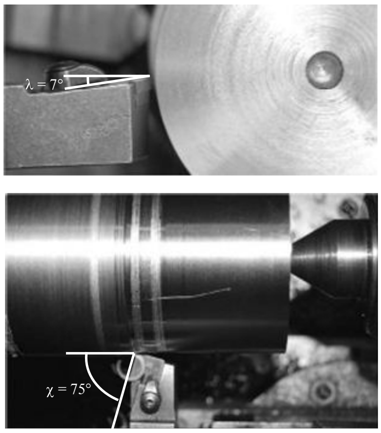

Fig. 1. Cutting operation set-up.

Table 1. AISI 1045 and ISO P40 chemical and mechanical specifications.

AISI 1045 chemical (% weight) and mechanical specifications	
%C	0.42÷0.50
%Mn	0.60÷0.90
%P	<0.040
%S	<0.050
Hardness Brinell [HB]	170
Ultimate Tensile Strength [MPa]	515
Yield Tensile Strength [MPa]	485
Elongation at break [%]	10.0
Reduction of area [%]	25.0
Modulus of elasticity [GPa]	200.0
Poisson ratio	0.290
Shear modulus [GPa]	80.0
ISO P40 chemical (% weight) mechanical specifications	
%W	82.8
%C	5.2
%Co	12.0
Hardness Rockwell A [HRA]	90
Ultimate Tensile Strength [MPa]	344
Modulus of elasticity [GPa]	670
Compressive Strength [MPa]	2683

DOE technique was applied for planning the experimental campaign. In this manner the influence of cutting speed (V_C), feed rate (f) and cutting time (t) on tool wear parameters was investigated.

Figure 2 shows the conduced experimental tests and the corresponding process parameters. Three levels were set for cutting velocity and feed rate (squares in Figure 2). As far as the cutting time is concerned, each test was carried out for 7 minutes and stopped at regular intervals of 30 seconds for measuring the extension of flank wear (VB) and the depth of crater wear (KT) for a total of fourteen intervals.