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# Response surface and neural network based predictive models of cutting temperature in hard turning

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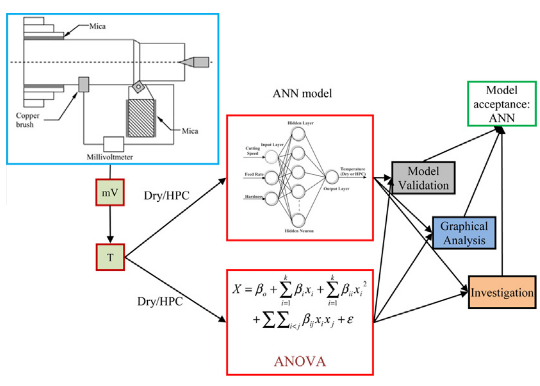
## GRAPHICAL ABSTRACT

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## ABSTRACT

The present study aimed to develop the predictive models of average tool-workpiece interface temperature in hard turning of AISI 1060 steels by coated carbide insert. The Response Surface Methodology (RSM) and Artificial Neural Network (ANN) were employed to predict the temperature in respect of cutting speed, feed rate and material hardness. The number and orientation of the experimental trials, conducted in both dry and high pressure coolant (HPC)

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environments, were planned using full factorial design. The temperature was measured by using the tool-work thermocouple. In RSM model, two quadratic equations of temperature were derived from experimental data. The analysis of variance (ANOVA) and mean absolute percentage error (MAPE) were performed to suffice the adequacy of the models. In ANN model, 80% data were used to train and 20% data were employed for testing. Like RSM, herein, the error analysis was also conducted. The accuracy of the RSM and ANN model was found to be ⩾99%. The ANN models exhibit an error of ~5% MAE for testing data. The regression coefficient was found to be greater than 99.9% for both dry and HPC. Both these models are acceptable, although the ANN model demonstrated a higher accuracy. These models, if employed, are expected to provide a better control of cutting temperature in turning of hardened steel.


## Introduction

The hard machining inherently possesses some of the major difficulties during the machining runs so as to hinder the process of achieving a higher quality of the product. Among several factors, cutting temperature is considered as the main culprit to ignite the difficulties. The adverse conditions, aroused from machining of hard material, can be properly addressed well before the actual machining, if and only, the outcome could be known far before the actual machining. Hence the necessity of computing the temperature of tool-workpiece interface is of great prevalence. Regarding this fact, many researchers have developed different models of cutting temperature in respect of different variables such as cutting speed, feed rate, and depth of cut.

In hard turning of steels, the material is hardened first, by proper heat treatment and, later put into the machining process to remove material and define the require shape. Herein, the metal cutting mechanics act differently than the machining of non-hardened steels. Drastic rise of temperature, in absence of cooling and lubrication, causes a detrimental effect on the tool and work material including the change in the microstructure. Karpat and Özel [1] analytically modeled the cutting temperature along with temperature distribution over the tool surface and found a good agreement between the experimental and predicted temperature. Liang et al. [2] developed an improved 3D model of chip-tool interface temperature in turning process of AISI 1045 steel by considering inverse heat conduction method. Pervaiz et al. [3] modeled cutting temperature of turning tool by considering the effect of flowing air surrounding the insert and the result helped to better understand the temperature scheme.

Sharma et al. [4] developed the optimization model of cutting temperature in turning AISI D2 steel under the application of different fluids using Taguchi method. The result revealed that the carbon nanotubes, when used with fluid, reduced cutting temperature effectively owing to the increase in heat transfer rate. Davoodi and Tazehkandi [5] investigated experimentally and optimized, using RSM, the cutting temperature in turning with an objective to eliminate cutting fluid. Yang and Natarajan [6] optimized the turning process parameters for the minimum tool wear and maximum material removal rate but without upsetting the cutting temperature limit. In other study, Umer et al. [7] optimized the cutting temperature using genetic algorithm but without compromising the power to cut and material removal rate. Moura et al. [8] investigated the capability of solid lubricant in reduction of chip-tool interface temperature during turning and concluded that the better lubrication is achieved with solid lubricant in suspension with oil.

The study on the application of cutting fluid, to reduce the cutting temperature, and consequently, lessen the adverse effects on the performances such as reduced tool wear, cutting force, and surface roughness, has been carried out by many researchers. Different fluid application methods such as minimum quantity lubricant [9,10], high pressure coolant [11,12], and cryogenic [13,14] establish themselves as viable alternative to dry cutting. Very few models [15,16] of chip-tool interface temperature have been developed by considering the machining environments/parameters. Hence, to better control the machining process, the prediction of cutting temperature is inevitable. To meet this objective, in this work, the response surface method and artificial neural network have been employed to model the cutting temperature in respect of cutting speed, feed rate and material hardness. It is also mentionable, using these methods, very few has incorporated material hardness as the input variable.

## Methodology

### *Machine, method and equipment*

In this work, three shafts of AISI 1060 steel (L = 200 mm, O.D. = 120 mm, I.D. = 45 mm) have been heat treated to achieve three hardness (H) values i.e. 40 HRC, 48 HRC and 56 HRC. The thermal treatment is performed in an induction furnace with appropriate heating element: firstly – by rising the temperature to 900 °C and holding at that temperature for 90 min, then suddenly reducing the temperature by oil quenching to attain a very high hardness, lastly – by raising the temperature to 375 °C, 235 °C and 150 °C for respective workpieces to remove excess hardness and brittleness. The results of hardness test are plotted in Fig. 1.

A powered center lathe (7.5 kW) was used to carry out the experimental runs on dry and high pressure coolant (HPC) applied turning. A sophisticated high pressure coolant supply system [12] has been employed to impinge the cutting oil to the tool-workpiece contact point. The cutting oil was supplied at 80 bar pressure, at a flow rate of 6 l/min, through external nozzle of 0.5 mm diameter. For better penetration and lubrication, the oil jet was aimed along the auxiliary cutting edge so that oil can reach under the flowing chips [11]. The coated (with TiCN, WC, Co) carbide insert (ISO specification-SNMM 120408) placed on PSBNR 2525 M12 holder has been used. The cutting speed (Vc) and feed rate (So) were chosen, keeping in mind the recent industrial practice, as 58, 81, 115 m/min and 0.10, 0.12, 0.14 mm/rev respectively. The depth of cut was maintained constant at 1.0 mm. These variables are oriented into 54 experimental runs (27 for dry cutting and 27