NAME OF THE SCHOLAR: SUHA KARIM SHIHAB
NAME OF SUPERVISOR(s): Dr. AAS MOHAMMAD (Supervisor) and PROF. ZAHID A. KHAN (Co-supervisor)
DEPARTMENT: MECHANICAL ENGINEERING
TITLE OF THESIS: EXPERIMENTAL STUDIES ON TURNING HIGH HARDNESS AALOY STEEL WITH HIGH PERFORMANCE TOOLS

ABSTRACT

In the present research, turning experiments on hard alloy steel (AISI 52100) using multilayer hard surface coated (TiN/TiCN/Al_2O_3/TiN) insert under three different machining conditions (dry, wet, and cryogenic) were performed. Three cutting parameters i.e. cutting speed (*A*), feed rate (*B*), and depth of cut (*C*), each at three levels were considered in the experimental studies. Experimental runs were performed as per the Central composite design (CCD) of experiment of response surface methodology (RSM) and data for various response variables were collected. Effect of the cutting parameters on the cutting force components, surface roughness average, micro-hardness, and surface integrity was investigated through statistical analyses of the collected experimental data. In addition, the effect of the cutting parameters on the cutting temperature and chip morphology i.e. tooth pitch, saw height, chip width, and chip thickness was also explored by analyzing the data collected only under dry turning condition. Relationship between the variables was established using quadratic regression model. Several diagnostic tests were also performed to check the validity of assumptions related to the residuals. Model equations were obtained to predict accurate values of the responses. Single and multi-response optimization was performed using desirability function to predict optimum value of response variables.

Analysis of results of turning under dry condition revealed that (i) all three cutting parameters, A^2, C^2, *AB*, and *BC* have significant effect on the thrust force (Fx), (ii) all three cutting parameters, B^2, C^2, *AB*, *AC*, and *BC* have significant effect on the tangential force (Fy), (iii) *B*, *C*, A^2, C^2, *AB*, *AC*, and *BC* have significant effect on the feed force (Fz), (iv) out of all three cutting parameters, the depth of cut has prominent effect on all cutting force components, (v) the range of best cutting parameters is cutting speed = 100 m/min to 118 m/min, feed rate = 0.10 mm/rev to 0.12 mm/rev, and depth of cut = 0.20 mm to 0.21 mm which results in the optimized value of cutting force components under dry condition, (vi) the results showed that *A*, *B*, B^2, C^2, *AB*, and *BC* all have significant effect on the surface roughness, (vii) the range of best cutting parameters is cutting speed = 223 m/min to 248 m/min, feed rate = 0.1 mm/rev to 0.11 mm/rev, and depth of cut = 0.54 mm to 0.96 mm which results in the optimized value of surface roughness, (viii) the results indicated that *A*, *C*, and *BC* have significant effect on the micro-hardness, (ix) the range of best cutting parameters is cutting speed = 143 m/min to 219 m/min, feed rate = 0.11 mm/rev to 0.20 mm/rev, and depth of cut = 0.23 mm to 0.82 mm which results in the optimized value of micro-hardness, (x) the range of best cutting parameters is cutting speed = (198 m/min to 201 m/min), feed rate = 0.1 mm/rev, and depth of cut = 0.76 mm to 0.90 mm which results in the optimized value of surface integrity i.e. surface roughness and micro-hardness, (xi) in case of chip morphology study under dry condition, the results indicated that the *B*, *C*, B^2, C^2, *AC*, and BC significantly affect the tooth pitch, (xii) *B*, *C*, *AC*, and *BC* significantly affect the saw height, (xiii) *A*, *B*, *C*, C^2, and *BC* significantly affect the chip width, (xiv) *A*, *B*, *C*, and *AB* significantly affect the chip thickness, (xv) the optimized value of chip parameters results from the best values of cutting parameters within the range cutting speed = 100 m/min to 249 m/min, feed rate = 0.10 mm/rev to 0.11 mm/rev, and depth of cut = 0.2 mm, (xvi) In case of cutting temperature study, the results revealed that *A*, *B*, *C*, B^2, *AB*, and *AC* significantly

affect the cutting temperature, (xvii) the range of best cutting conditions that yield optimum cutting temperature is: cutting speed = 100 m/min to 102 m/min, feed rate = 0.12 mm/rev to 0.15 mm/rev, and depth of cut = 0.59 mm to 0.93 mm which results in the optimized value of cutting temperature.

Analysis of results under wet condition revealed that (i) *A*, *B*, *C*, B^2, C^2, *AC*, and *BC* significantly affect the thrust force and feed force, (ii) *A*, *B*, *C*, B^2, *AC*, and *BC* significantly affect the tangential force, (iii) the range of best cutting conditions that yields optimum cutting force components is: cutting speed = 100 m/min to146 m/min, feed rate = 0.10 mm/rev to 0.13 mm/rev, and depth of cut = 0.2 mm, (iv) *A*, *B*, *AC*, and *BC* significantly affect surface roughness, (v) the range of best cutting conditions that yields optimum surface roughness is cutting speed = 100 m/min to 226 m/min, feed rate = 0.1 mm/rev, and depth of cut = 0.20 mm to 0.21 mm, (vi) *A*, *B*, A^2, B^2, C^2, *AC*, and *BC* significantly affect micro-hardness, (vii) the range of best cutting conditions that yields optimum micro-hardness is: cutting speed = 122 m/min to 242 m/min, feed rate = 0.12 mm/rev to 0.20 mm/rev, and depth of cut = 0.41 mm to 0.94 mm, (viii) the range of best cutting conditions that yield optimum surface integrity is: cutting speed = 127 m/min to 250 m/min, feed rate = 0.1 mm/rev, and depth of cut = 0.20 mm to 0.82 mm.

Analysis of results under cryogenic condition showed that (i) *B*, *C*, A^2, B^2, and C^2 significantly affect thrust force and feed force, (ii) *B*, *C*, A^2, and B^2 significantly affect tangential force, (iii) the range of best cutting conditions that yields optimum cutting force components is: cutting speed = 100 m/min to 250 m/min, feed rate = 0.10 mm/rev to 0.16 mm/rev, and depth of cut = 0.22 mm to 0.27 mm, (iv) *A*, *B*, A^2, and *AC* significantly affect surface roughness, (v) the range of best cutting conditions that yields optimum surface roughness is: cutting speed = 212 m/min to 225 m/min, feed rate at 0.1 mm/rev, and depth of cut = 0.99 mm to 1.00 mm, (vi) *A*, *B*, A^2, C^2, and *BC* significantly affect micro-hardness, (vii) the range of best cutting conditions that yields optimum micro-hardness is: cutting speed = 103 m/min to 239 m/min, feed rate = 0.11 mm/rev to 0.22 mm/rev, and depth of cut = 0.21 mm to 0.81 mm, (viii) the range of best cutting conditions that yield optimum surface integrity is: cutting speed = 196 m/min to 223 m/min, feed rate = 0.11 mm/rev, and depth of cut = 1.00 mm.

It has been observed from the results that all three force components in cryogenic machining are lesser than those of dry machining and wet machining. Further, the values of surface roughness and micro-hardness under dry condition are lesser than those under wet and cryogenic condition.

Tool wear was also studied through a separate set of experiments using Taguchi's L_9 orthogonal array. The results of the study revealed that (i) lower levels of cutting parameters i.e. *A* at 100 m/min, *B* at 0.1 mm/rev and *C* at 0.2 mm ($A_1B_1C_1$) yield the minimum flank wear, (ii) *A* and *B* significantly affect the flank wear. The levels of the cutting parameters that produced maximum flank wear in dry condition were identified and machining under wet condition at these levels was performed and flank wear under dry and wet conditions was compared. A micro-channel was devised in the insert to effectively deliver the cutting fluid directly at the tool-chip interface and turning experiment was performed with the tool insert with micro-channel. The results revealed that (i) provision of micro-channel reduces the flank wear by 48.87% and 3.04% as compared to dry and wet machining respectively, and (ii) tool with micro-channel results in a saving of volume of cutting fluid consumed and energy by about 87.5% as compared to wet machining.

The possible reasons for the results presented above have been explained in light of the findings of the previous researchers. Further, the effect of individual and combined cutting parameters on the response variables has been demonstrated and discussed through perturbation plots and 3-D surface plots respectively. In addition, model equations to predict the values of different response variables have been obtained and the predicted and actual (experimental) values have been compared. The comparison results have shown that the predicted values are in close agreement with the actual values.