Effects of Temperature Variation on the Cutting Edge Hardness of Selected HSS and HCS Single Point Cutting Tools

B. Kareem, S.F. Daramola

Abstract— **Cutting tool life depends on the degree of resistance to wear on the cutting edge. Temperature rise due to heat generated in work piece and cutting tool interface was found to be responsible for tool wear. Dry cutting is necessary to prevent corrosive effect of coolants. On this basis, Rockwell class 'A' (HRA) hardness test was employed in testing the hardness of four selected single point cutting tools at varying temperature. The tools are High Speed Steel (HSS) tools (M4 and M1), and High Carbon Steel (HCS) tools (Q275 and A36) according to Society of American Engineers (SAE) steel grades. The temperature variation was achieved by heating the samples in a digital electric furnace at varying temperature from 150 ^{o}C to 750 ^{o}C as specified by the SAE standard, in step of 50^{o}C. The hardness number was read directly through a digital display unit of the Identec hardness tester, while determining the hardness of the cutting edge (tip) of the tool. The results obtained were analyzed using statistical regression model. From the experimental results, the high speed steel tools showed better hardness at higher temperatures than High carbon steel tools. The range of temperature that supported dry cutting was predicted.**

Index Terms—**Cutting Tools, Hardness, Dry Cutting, Temperature range, Work piece Material**.

I. INTRODUCTION

Single point cutting tools are critical in machining operations especially on lathe and shaping machines. During machining, temperature of the tools tend to increase thereby making the tools susceptible to wear. The tool wear rate depends largely on the hardness of work piece material, speed and feed of cut, cutting conditions (dry or wet) and tool material. The stated factors, summarily determine tool life which is an economic indicator of how well the metal cutting operations is performing. It is clear that long tool-life has better economic value than short tool-life [10, 24].

Property requirements of tools to have a long life were well stated in literature [4, 19, 22]. Many researchers have attempted to develop improved tool materials to sustain wear challenges [10, 22, 24]. Turning operations have been found prominent in experimental investigation of tool wear [7, 23]. Easy measurement of wear on the flank (tip) of the cutting tool or high demand of turning jobs could be a reason [12, 16]. High temperature, which is a major contributor to tool wear arises as a result of heating effect of friction between the tool and the work piece during cutting operations. Coolants can reduce heat but it was additional cost beside corrosion effect it has on machine, tools and work piece. This limitation has led to development of tool materials and coatings in which coolant application may not necessary during machining operations [23, 25]. Alternative method of tooling devoid of coolant can be developed through balancing of work piece and cutting tool properties with special consideration to temperature and hardness. Under this platform, simplification through testing of heat resistance (temperature) level of existing tools in order to determine (predict) possibility of using them at a certain temperature range without hardness loss during machining operations.

The objective of this study is to develop hardness loss prediction model for selected HSS and HCS single point cutting tools under varying temperature. Experiment was carried out by measuring tip hardness of the tools under varying temperature in static condition. Furnace and electronic digital hardness tester was used for the measurement of the stated parameter during experimentation. Tool failure was determined at the point where there was a sharp decrease tip hardness.

Many studies were carried out in literature on temperature and tool hardness. These studies included: cutting temperature control [20, 21]; tool failure modes due to high temperature [19]; cutting tool temperature distribution during machining operations [18]; tool- chip interface temperature analysis [10, 14]; tool temperature analysis under hardened steel machining operations [1]; cutting zone temperature variation prediction by thermocouple technique [2, 4]; cutting temperature and integrity of machined surface analysis [13]; established numerical analysis for cutting parameters including temperature [8, 9]; and mechanisms of tool wear analysis [11, 15, 17]. None of the stated studies considered temperature variation with cutting tool tip-hardness simultaneous under the experimental framework. Besides, non-modelling of cutting edge hardness of single point cutting tools at varying temperature for prediction purpose is another area that needs attention. In this study the stated gaps were addressed by carrying out experimental study on the cutting tip hardness at varying temperature and modelling of the outcomes using statistical regression technique.

There exist a myriad of cutting tool material; these included HSS, HCS, cemented carbides, ceramics, cubic boron Nitride, and diamond [3, 5]. This study focused on the first two materials because of availability of the tools, and usability in many mechanical workshops. Determination of tool life and tool wear of single point cutting tools was made simple by prediction through modelling tool tip (flank) - hardness due to temperature variation. The single point cutting tool nomenclature is shown in fig. 1. It comprises cutting edge, rake face, flank face, nose and shank [6, 12]. Hardness variation of the tool's cutting edge /flank face (cutting tip)

B. Kareem, Mechanical Engineering Department, Federal University of Technology, Akure, Nigeria, +2348033737251

S.F. Daramola, Mechanical Engineering Department, Federal University of Technology, Akure, Nigeria, +2348163060320

with the change in temperature was studied and the results presented in this paper.

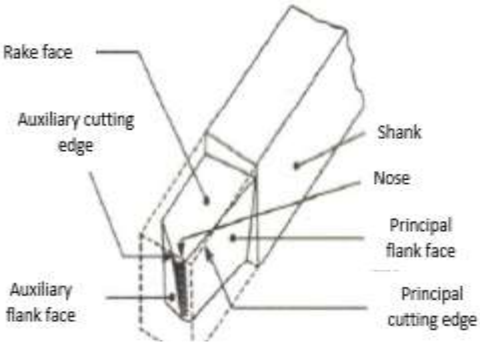

Fig.1. Single point cutting tool geometry

II. MATERIALS AND METHOD

A. *Materials*

Four selected single point cutting tools were tested for their hardness within a temperature range of 150^0C - 750^0C, in step of 50^0C. The selected tools are High Speed Steel (HSS) tools of models M4 (standard) and M1 (intermediate)(according to the Society of American Engineers, SAE steel grades and under the class of T11304 and T11301 respectively according to American Iron and Steel Institute, AISI classification), and High Carbon Steel (HCS) tools of models Q275 (standard) and A36 (intermediate) (according to SAE steel grades and under the class of AISI 1561 and AISI 1095 respectively according to AISI classification). The chemical composition of the tools are shown in table 1. The presence of higher percentage of carbon, tungsten and some vital alloying elements in the chemical composition of high carbon steel (HCS) and high speed steel (HSS) tools were responsible for the superiority of the standard tool steels over the intermediate tool steels (table 1).The choice of high carbon steel and high speed steel materials for experimental work is principally because of the ability of these materials to retain their hardness at reasonably high temperatures under a permissive range of cutting parameters. Besides, the tools have wide applications in most lathe cutting/turning operations. Other major materials used for the experiment are digital electric furnace and a Rockwell class A hardness measuring machine known as Identic. The chemical composition results shown in table 3 are similar to the tools' manufacturers' specifications.

Table 1 Chemical Composition of the base materials in Tool Steel Samples (wt %)

Elements	HSS 1 (wt %)	HSS 2 (wt %)	HCS 1 (wt %)	HCS 2 (wt %)
Carbon (C)	1.33	0.83	0.90	0.70
Silicon (Si)	0.33	0.33	0.60	0.40
Chromium (Cr)	4.13	3.75	0.80	0.60
Vanadium (V)	2.50	1.18	-	-
Tungsten (W)	5.88	1.75	-	-
Molybdenum (M)	5.63	8.70	1.10	1.05
Manganese (Mn)	-	-	0.90	-
Copper (Cu)	-	-	0.55	0.45
Nickel (Ni)	-	-	-	0.3
Sulphur (S)	-	-	-	0.05

B. *Experimental*

The aim of the experiment is to determine how the hardness of the cutting tools vary with temperature change. The objective is to determine the permissive temperature range at which the individual cutting tool can retain its hardness before failure. The type of hardness test employed for this experimental work is Rockwell A class hardness test. This test method by application of force proved to be a major advance in the world of hardness testing. It enabled the user to perform an accurate hardness test on a variety of sized parts in just a few seconds. The type of hardness tester used for this experimental work is shown in fig. 2. The Model -4150AK digital Rockwell hardness tester is a mechanical/electrical hardness testing instrument, which comprises; digital display device, microcomputer control lift, release screw and automatic feedback lock, rotary wheels, and printer. The machine was designed to completely eliminate error and Produced in 2007 by Indentec Hardness Testing Machine Limited, West Milando, United Kingdom. For this tester, force application, indentation, hardness value display, and general operational automation methods are simplified.

Fig. 2 Model -4150AK Digital Rockwell Hardness Testing Machine

Fig. 3.Digital Electric furnace (Blast Air Oven of KX350A Model)

Other notable Equipment used for the experimental work include: a digital electric furnace called 'blast air oven' of KX350A model produced by KENXIN International Company Limited (Fig. 3); a motorized reciprocating compressor; and a spring controlled tongue.

The four samples of cutting tool steel were tested for their hardness within a temperature range of 150^0C - 750^0C, in step of 50^0C. The type of hardness test employed was Rockwell class 'A' (HRA). The type of penetrator used is diamond (brale) of 10kgf minor load and 60kgf major load. Tests were made with the Rockwell hardness tester by applying two loads on the part to be tested. The first load was the minor load, the second, the major load. The Rockwell tester measured the linear depth of penetration. The difference in depth of penetration produced by applying a minor load and then a major load was translated into a hardness number. This number was read directly by using a digital display unit on the Identec hardness measuring machine in the experimental work under consideration.

A shallow penetration indicates a high degree of hardness and a high hardness number. A deep penetration indicates a lower degree of hardness and a low hardness number. In general, the harder the material, the greater its ability to resist deformation. Different penetrator points are used on Rockwell testers depending on the hardness of the material. Diamond (brale) penetrator of 10kgf load was used for this experimental work and this is referred to as minor load. The samples are first heated in a digital electric furnace (Fig. 3) to the required temperature and then placed on the measuring surface (anvil) of a digital hardness measuring machine known as Identec which displayed the hardness at that temperature after the required impact has been given to the sample by the diamond penetrator. The hardness of each sample was determined at every 500C up to final temperature of 750^{o}C. Readings were taken at cutting tool tip (flank) three/four times for each of the tools (table 2). Average values of the three/four readings to the nearest whole numbers were then determined and chosen as the hardness number as shown in table 3.

For each experimental run, anvil and indenter of the hardness tester were properly cleaned and seated well. Seating test using a material having a uniform hardness was carried and repeated until successive measurement values showed no trend of increasing or decreasing hardness. Tools (samples) were placed on the anvil by means of spring controlled tongue. The contact area between a well-supported test material and the anvil was cleansed of dirt, dust or lubricant using ethyl alcohol and dried with lint free cloth and filtered air. During the experimental run, indenters and anvil were protected from damage/scratch. The effect of Rockwell hardness testing cycle was assumed to be negligible on the hardness measured. The summary of the experimental steps is as follows: select and mount the appropriate penetrator/indenter and anvil in the hardness tester; put on the digital display unit (identec) power source and prepare it for the measurement; place the steel sample on the anvil; raise the anvil or lower the penetrator until it touches the tool sample; apply the minor load (this load is shown on the digital display unit), and set the hardness reading of the indicator at zero; apply the appropriate major load; reduce the kgf of the major load to the setting of the minor load; read the hardness from the digital display unit; reduce the minor load, move the tool cutting tip/edge to second, third or fourth location; record the hardness readings; and average the three/four hardness readings to determine the hardness value.

C. *Modelling Method*

The results obtained from the experimental tests on the four different tool samples were analyzed using statistically regression model. For each regression equation, outcome of coefficient of determination showed a strong representation of experimental data. The most fitted hardness regression model for the tool sample was polynomial out of the list of statistical regression models tested namely: linear, logarithmic, inverse, quadratic, cubic, compound, power, growth, polynomial and exponential models. The chemical composition, experimental and modelling outcomes were discussed in the following section.

III. RESULTS AND DISCUSSION

A. *Chemical Composition Results*

The standard high speed steel tool of M4 grade has a high carbon content of 1.33% and it has a high percentage of both tungsten (5.88%) and molybdenum (5.63%) which principally accounts for its superiority over the intermediate high speed steel tool. The intermediate high speed steel tool is a relatively high alloy of speed steel of M1 grade with 0.83percent carbon (table 1). Although it has a high percentage of molybdenum (about 8.70%) in its chemical composition, the non-availability of cobalt and its relatively low percentage of other alloying elements like tungsten accounts for its inferiority over the standard high speed steel tool. However, the percentage of alloying elements in both high speed steel tools under experimental test is relatively a little above 10%.

The standard high carbon steel tool is a low alloy carbon steel of the Q275 grade having carbon content of 0.9% with other alloying elements in various proportions as specified in the table 1. The less availability of trace impurities and the presence of some alloying elements in reasonably high percentage accounts for the superiority of standard high carbon steel tool over the intermediate type. The intermediate high carbon steel is a relatively low alloy carbon steel of A36 grade with 0.70%carbon content. The presence of trace impurities of other elements like sulphur (about 0.05%) in the intermediate high carbon steel has a significant adverse effect on its quality. Its melting point is around 1426 – 1538^{o}C. The percentage of alloying elements in both high carbon steel tools under experimental test is below 5%.

B. *Experimental Test Results*

The results of the tests carried out on four different samples of steel tool materials are shown in tables 2 and 3. From the results, the Standard High Speed Steel (HSS1) tool retained its hardness of 77 HRA till 500^{0}C before reduction occurred at a moderate rate up to 6500C. After this temperature geometric reduction in hardness took place up to the maximum temperature, 750^{0}C. Between 7000C and 750^{0}C, the tool can no longer function properly as wear/weakness was set in due to drastic reduction in hardness.

The Intermediate High Speed Steel (HSS2) on the other hand has a lower hardness of 72 HRA at 150^{0}C which it retained up to 450^{0}C. Between 500^{0}C and 600^{0}C, gradual reduction in hardness was set in. Above these temperatures, higher and steadily reduction in hardness occurred as low as 41 HRA, thereby rendering the tool unsuitable for certain machining operations. However, re-sharpening of the cutting edge or re-hardening of the tool surface can be carried out as a solution to this challenge.

Generally, it was deduced from the results (table 3) that the Standard High Speed Steel is harder than the Intermediate type. For example at 150^{0}C, HSS1 had a hardness of 78 HRA which was higher than that of HSS2 with hardness of 72 HRA.

Similarly, at 750^0C, HSS1 had a hardness of 52 HRA while HSS2 had 41 HRA.

The Standard High Carbon Steel (HCS1) tool hardness value of 68 HRA at 150^0C was maintained only up to 250^0C. Slight reduction in hardness value was recorded between 300^0C and 450^0C. Beyond this, considerable reduction in hardness value was noticed. Hence, tool hardness (30HRA and 40HRA) at this temperature can only support machining of the plastic materials or other softer metals.

The intermediate high carbon steel (HCS 2) on the other hand has almost the same hardness with HCS1 at 150^0C up to 200^0C with just very little variation with similar mean values (table 3). At 250^0C, gradual reduction in hardness values were recorded up to 300^0C. Above this temperature, the hardness value began to fall sharply and stabilized at 26 HRA, 750^0C.

In comparison, HCS1 tool was slightly harder than HCS2 at lower temperature, 150^0C- 200^0C. At temperature range of 250^0C - 450 ^{0}C, the difference in hardness became pronounced as HCS1 almost maintained its initial hardness of 68 HRA at 150^0C - 450^0C , while HCS2 hardness decreased sharply from 68 HRA at 150^0C to 38 HRA at 450^0C. The technical indication of this is that HCS1 can still be used to machine even harder materials up to a temperature of 450^0C while HCS2 can only be used successfully up to 250^0C.

It can be concluded that the High Speed Steel (HSS1&2) tools can be viably used without loss of hardness within temperatures of 650^0C and 450^0C respectively, while the High Carbon Steels (HCS1&2) tools were operable within temperature limits of 300^0C and 200^0C, respectively (fig. 4).

C. Modelling Results

Regression model summary obtained from experimental results for hardness prediction of the cutting tools are presented by equations 1-5. Polynomial models of order three (3) were found to be optimal because it possessed best/highest coefficients of determination. This characteristics made its predicted hardness values similar to experimental outcomes in table 3. On this basis, polynomial model was found to give the best fit of experimental data out of regression models considered, namely; linear, logarithmic, inverse, quadratic, cubic, compound, power, growth, polynomial and exponential. Therefore, Rockwell hardness numbers predicted was formulated as:

$$HRN = \left[a + bT + cT^2 + dT^3\right] \tag{1}$$

HRN, is Rockwell Hardness Number; a, b, c, and d, are the coefficients of various degrees of temperature, and T, is temperature in degree Celsius. The Rockwell Hardness Numbers (HRN) prediction model results are presented in “(2-5)” for the four tools’ hardness outputs by applying the regression “(1)”. HRN_{HSS1} is the Rockwell hardness Number for standard High Speed Steel tool referred to as M4 , HRN_{HSS2} is that of intermediate High Speed Steel referred to as M1 ; while, HRN_{HCS1} and HRN_{HCS2} are for standard High Carbon Steel and intermediate High Carbon Steel tools respectively.

$$HRN_{HSS1} = 82.465 - 0.092T - 4*10^{-7}T^3 \tag{2}$$

$$HRN_{HSS2} = 71.292 - 0.0011T + 7.55*10^{-5}T^2 - 1.83*10^{-7}T^3 \tag{3}$$

$$HRN_{HCS1} = 61.812 + 0.102T + 2.42*10^{-7}T^3 \tag{4}$$

$$HRN_{HCS2} = 67.22 + 0.058T + 3.68*10^{-7}T^3 \tag{5}$$

Table 2. Hardness Variations with Temperatures

TEMP (°C) / TOOLS	150	200	250	300	350	400	450	500	550	600	650	700	750
HSS 1 (HRA)	77.7 77.8 77.7 77.7	77.7 77.7 77.7 77.7	77.7 77.5 77.7 77.8	77.7 77.8 77.6 77.7	77.6 77.7 77.6 77.7	77.7 77.5 77.5 78.1	77.7 77.5 77.8 77.7	77.4 77.7 77.8 77.7	75.0 75.1 74.8 75.1	75.1 75.1 74.9 74.9	74.1 74.1 74.4 74.4	55.9 56.1 56.0 56.1	51.7 47.9 52.0 52.1
HHS 2 (HRA)	72.5 72.7 72.5 72.5	72.0 71.9 72.3 72.4	72.1 72.1 72.0 72.0	72.0 71.1 70.0 71.1	72.1 72.1 72.4 72.0	72.0 72.0 72.1 72.0	66.4 66.4 67.7 67.7	65.2 65.0 65.2 65.2	65.2 65.0 65.2 65.2	64.6 64.8 64.0 64.6	43.2 44.9 43.2 42.3	42.1 42.0 42.3 42.0	40.7 40.7 40.5 40.5
HCS 1 (HRA)	68.5 68.4 68.7 68.5	68.5 68.6 67.9 68.5	68.5 68.4 67.9 68.5	66.6 67.8 66.6 66.4	63.4 63.2 63.1 63.2	63.5 63.1 63.4 63.4	63.4 63.4 63.1 63.4	47.3 47.3 47.2 47.3	44.2 45.7 45.8 45.8	42.9 42.9 42.5 42.8	40.8 40.9 40.8 40.8	38.8 39.2 39.9 39.9	35.2 35.1 35.1 35.4
HCS 2 (HRA)	68.5 68.2 68.5 68.3	67.4 68.1 68.5 68.5	64.4 66.0 64.3 64.4	63.1 61.2 61.1 61.1	48.3 48.3 48.5 47.1	43.5 43.5 44.6 43.5	38.5 38.2 38.2 38.4	35.6 37.1 37.1 35.7	35.4 35.1 35.1 35.1	43.0 34.1 34.0 34.0	32.0 32.0 32.0 32.0	31.1 30.1 31.0 31.1	26.3 26.3 26.3 26.3

Table 3. Mean Hardness Test Results

TEMP (^{0}C)/ TOOLS (Type)	150	200	250	300	350	400	450	500	550	600	650	700	750
HSS 1	77	77	77	77	77	77	77	77	75	75	74	56	50
HSS 2	72	72	72	72	72	72	72	66	65	64	43	43	40
HCS 1	68	68	68	66	63	63	63	47	45	42	40	39	35
HCS 2	68	68	64	61	48	43	38	36	35	34	32	31	26

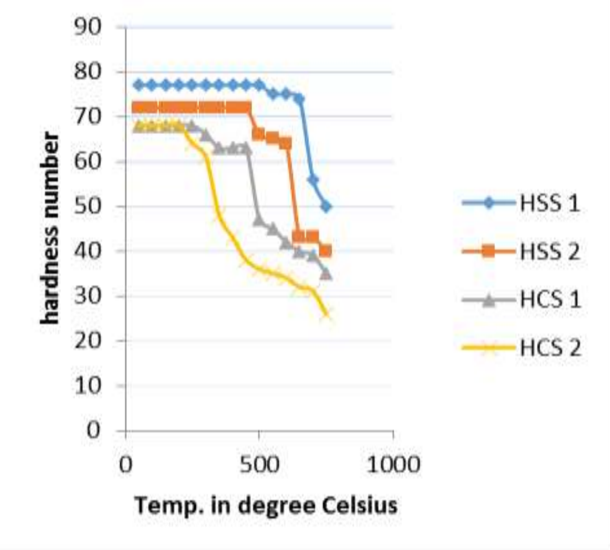

Fig. 4. Hardness Variation with Temperature

IV. CONCLUSION

Dry cutting required the cutting tools to be made of material harder than the material to be cut, and the tool must be able to withstand the heat generated in the cutting process too. Hardness testing is an important and useful tool in material testing that determines quality and performance of the cutting tools. The Rockwell Hardness testing technique is one of the best methods for determining hardness of cutting tools at varying temperature under wet or dry cutting condition. Test under dry cutting condition is more popular than wet because of the need for preventive measure of corrosion caused by coolants on cutting tool and work piece.

Variation in cutting edge (tip) hardness of selected HSS and HCS single point cutting tools with change in temperature was experimentally studied under the Rockwell class ‘A’ hardness technique. Statistical Package for Social Sciences (SPSS) Version 16.0 for Window was for modelling. From the analysis of the experimental results, third-order polynomial regression model adequately fitted the tool hardness variation with change in temperature for the M1, M4 High Speed Steel and Q235, A36 High Carbon Steel tools. The model was highly correlated with experimental data and hence produced satisfactory results with minimum error. The established regression models can accurately predict the corresponding hardness of the stated cutting tools at a given temperature during machining operation.

The findings showed that the temperature and the corresponding hardness values obtained from the experiment were in consonant with SAE standards. This indicated that the experimental method is a good alternative to the complex methods of determining tool hardness. Besides, range of temperature that the cutting tools can survive dry cutting and the appropriate work piece materials were suggested. Optimal selection of tool hardness and temperature for dry cutting operation will enhance process optimization, productivity and cutting economy.

ACKNOWLEDGMENT

The management of the Federal University of Technology, Akure, Nigeria is acknowledged for providing facilities utilized for this study.

REFERENCES

[1] A. Abbas, and M.N. Minhat, 2013, “A Mild Steel Shear Zone Temperature Minimization using Genetic Algorithm and Direct Search Toolbox in CNC Turning Operation”, International Review of Mechanical Engineering, 7(1), 38-45.
[2] H. Ay and W.J. Yang, 1998, “Heat Transfer and Life of Metal Cutting Tools in Turning”, International Journal of Heat and Mass Transfer, 41, 613-623.
[3] G. Boothroyd G. and W.A. Knight, 1989, “Fundamentals of Machining and Machine Tools”, 2nd Ed., Marcel Dekker Inc., New York.
[4] S.K. Choudhary and G. Bartarya, 2003, “Role of Temperature and Surface Finish in Predicting Tool Wear using Neural Network and Design of Experiments”, International Journal of Machine Tools and Manufacture, 43, 747-753.
[5] P. Collier and B. Parkinson, 1980, “Workshop Process and Materials. 2nd Ed. Anchor Publications, London.
[6] S. Crawford, 1972, “Basic Engineering Processes”, 2nd Ed. Arrowsmith Publications, London, pp.73- 85.
[7] M.A.R. Federico and L.B. Coelho, 2008, “Turning Hardened Steel using Coated Carbide at High Cutting Speeds”, Journal of the Brazilian Society of Mechanical Science and Engineering, xxx. (2), 1109.
[8] M. Gostimirovic, P. Kovac and M. Sekulic, 2011, “An Inverse Heat Transfer Problem for Optimization of the Thermal Process in Machining”, Sadhana- Indian Academy of Sciences, 36, 489–504.
[9] W. Grzesik, 1999, “Experimental Investigation of the Cutting Temperature when Turning with Coated Index-able Inserts”, International Journal of Machine Tools and Manufacture, 39, 355-369.
[10] M. Haddad, R. Zitoune, F. Eyma, and B. Castanié, 2013, “Machinability and Surface Quality during High Speed Trimming of Multi-directional CFRP”, International Journal of Machining and Machinability of Materials, 13(2-3), 289-310.
[11] R.W. John, 1989, “Machining Fundamentals (from basics to advanced techniques)”. 4th Ed. Willcox Publications, U.S.A.
[12] B. Kareem, 2010, “Manufacturing Process, Vol.II: Cutting Production Methods”, Besade Publishing Press, Ondo, Nigeria.
[13] H.A. Kishawy and M.A. Elbestawi, 1998, “Effect of Edge Preparation and Cutting Speed on Surface Integrity of Die Materials in Hard Machining”, ASME International Eng. Congr, Exp. Manf.Sci, Technology, pp. 269-276.
[14] E.G. Lowen, and M.C. Shaw, 1954, “The Analysis of Cutting Tool Temperatures”, Transactions of the ASME, 76, 217-231.
[15] P.L.B. Oxley, 1989, “Mechanics of Machining- An Analytical Approach to Assessing Machinability, Halsted Publication, New York, pp. 72-85.
[16] Z. Pálmai, 2003, “Proposal for a New Theoretical Model of the Cutting Tool's Flank Wear”, 303(1-2), 437-445.
[17] P.C. Pandey, and H.S. Shan, 1981, “Modern Machining Processes”. Mcgraw-Hill Publications, New Delhi, pp. 7-51.
[18] V. Schulze, ; J. Michna, F. Zanger, C. Faltin, U. Maas and J. Schneider, 2013, “Influence of Cutting Parameters, Tool Coatings and Friction on the Process Heat in Cutting Processes and Phase Transformations in Workpiece Surface Layers”, HTM - Journal of Heat Treatment and Materials, 68(1), 22-31.

[19] J.P.K. Sonia, N.K. Mehta and V. Upadhyay, 2013, "Effect of Cutting Tool Geometry on Tool Wear and Tool Temperature during Ti-6Al-4V Machining", International Journal of Mechanical and Materials Engineering, 8 (1), 32-39.

[20] D.A. Stephenson and P. Bandyopadhyay, 1997, "Process Independent Force Characterization for Metal Cutting Simulation", ASME Journal of Engineering Materials & Technology, 119, 86-94.

[21] D.A. Stephenson, 1992, "Tool–work Thermocouple Temperature Measurements: Theory and Implementation Issues", Proceedings of Winter Annual Meeting of ASME, Anaheim CA. pp-18-95. November.

[22] R.J. Talib, A.A. Mahaidin, S.A. Manaf, M.F. Fazira, and M.A. Selamat, 2013, "Effect of Compaction Load and Heat Treatment in Manufacturing of HSS Cutting Inserts under Nitrogen-based Atmosphere", Advanced Materials Research, 686, 313-319.

[23] D.G. Thakur, B. Ramamoorthy and L. Vijayaraghavan, 2013, "Influence of Minimum Quantity Lubrication on the High Speed Turning of Aerospace Material Super-alloy Inconel 718", International Journal of Machining and Machinability of Materials, 13 (2-3), 203-214.

[24] E.M. Trent, 1991, "Metal Cutting", 3rd Ed. Hartnolls Publications, Cornwall.

[25] T. Yashiro, T. Ogawa and H. Sasahara, 2013, "Temperature Measurement of Cutting Tool and Machined Surface Layer in Milling of CFRP", International Journal of Machine Tools and Manufacture, 70, 63-69

B. Kareem holds B.Eng., M.Eng. and PhD degrees in Mechanical Engineering, Production Engineering and Industrial Engineering respectively. He published well in the area of Industrial and Production Engineering in reputable engineering and professional journals. He is a member of many engineering professional bodies including World Assembly of Science, Engineering and Technology. He has many years of teaching and research experience. He has worn academic prizes including best researcher of the year in 2011 at his own University.

S. F. Daramola holds M.Eng. in Production Engineering from the Federal University of Technology Akure, Nigeria. He is a research student in the same field.