Generation of Temperature Rise Distribution at Chip of EN31 Steel Due to Primary Deformation Zone during Turning Using MATLAB® and to Study its Machinability Behavior with CVD Carbide Insert

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Abstract --- **Temperature rise at chip during machining leads to formation of built up edge, reduced tool life and poor surface finish. In this paper, one of the author's coding at MATLAB® is modified with small changes to determine temperature rise distribution at chip side due to primary deformation zone. The modified coding is a simplified program of an analytical model, linked with basic machining parameters and is expected to obtain temperature rise contour in few seconds during starting of turning operation. The modified coding is validated using already obtained results of scientists.**

The developed coding is used for EN31 Steel when turned with MTCVD coated carbide inserts. The work is carried out with number of turning operations on DRO lathe machine. Dynamometer & Digital Vernier are used as accessories to measure developed forces during machining & chip thickness respectively during each operation. The machining data is collected and is used to generate temperature rise contour graphs for every experiment from developed coding. A study of variation of developed forces & maximum temperature rise at chip during machining has also been done with respect to cutting parameters.

It was seen that cutting parameters are directly proportional to developed forces and temperature rise during machining. Influence of Cutting Velocity is most and Depth of Cut is least in varying the forces and temperature rise.

Keywords--- **Machining, temperature rise, cutting force, shear zone, analytical modeling, MATLAB**

I. INTRODUCTION

A lot of input energy during machining gets converted into heat energy due to formation of deformation zones (primary, secondary & tertiary). This heat further results in rise of temperature at tool, chip & work piece which if exceeds a limit; directly affects the machinability by introducing wear, fracture, flaking, dimensional inaccuracy, BUE formation, development of stresses and so on at work piece, chip & tool.

Temperature rise generation at chip often leads to formation of undesirable quality of chip, reduced tool life and poor surface finish. This can be controlled by controlling the machining parameters [1] and it was also rectified that temperature rise at chip is same as temperature rise at tool [2]. So it is worth to have an estimation of temperature rise distribution at chip side very initial to actual manufacturing for various cutting parameters so that machinability can be improved.

There are basically three methods to determine temperature rise distribution at tool, chip and work piece namely, experimental [3], numerical and analytical [4, 5]. Each of them is having their respective merits and demerits [4, 5].

In the paper, an analytical model (with a complex equation) [6] is taken as a base for the work which is used to determine temperature rise distribution at chip due to primary deformation zone for any set of machining parameters for turning process. This equation is difficult to understand, requires lot many input parameters (directly or indirectly connected to modelling equation) and could not be solved at any easily available mathematical software in less time. In order to simplify this equation, an idea is generated to relate it with basic machining parameters followed by its step by step evaluation. A similar work has been done in one of the author's article using MATLAB® coding where a modelling equation was simplified in step by step manner and co-related with cutting parameters [7]. It is seen that this coding with a small change can be used to evaluate based modelling equation. The modified coding is validated with previously obtained results of a researcher prior to its application on EN31 Steel. This modified coding is used in the article to determine temperature rise generation at EN31 Steel when turned with MTCVD coated carbide insert at DRO lathe machine for various cutting parameters. Developed forces for each turning operation are measured using DKM2010 dynamometer and chip thickness is measured by Digital Vernier. EN31 steel is taken for machining because of its wide applications in bearings, spinning tools, beading rolls, punches and dies. This type of steel has high resisting nature against wear and can be used for components which are subjected to severe abrasion, wear or high surface loading. An analysis of cutting forces and temperature rise distribution with respect to cutting parameters has also been done in study.

Section 2 of the article states the analytical model used in the work followed by generation of MATLAB® coding of its equation in section 3. Validation of the coding is done in section 4. Section 5 deals with collection of machining data and application of coding with obtained data to generate temperature rise contour graphs followed by analysis of results. Section 6 & 7 specifies conclusion and future scope of the work.

II. ANALYTICAL EQUATION

Komanduri and Hou [6] got a latest success to develop an accurate analytical model capable of determining temperature rise distribution at chip side due to primary deformation zone. Pertaining equation developed from the model is given as equation (1). Assumptions used to evaluate the modeling equation are same as used by A. Goyal et.al [7] in his work. Abbreviations used in the work are given in appendix.

$$\theta_{chip-primary} = \frac{q_{shear}}{2\pi k}\int_{l_i=0}^{L_{ab}} e^{-(X-l_i\sin(\emptyset-\alpha))\frac{V_c}{2a}}\{K_0\left[\frac{V_c}{2a}\sqrt{((X - l_i sin(\emptyset-\alpha))^2 + (Z - l_i cos(\emptyset-\alpha))^2)}\right] + K_0\left[\frac{V_c}{2a}\sqrt{((X - l_i sin(\emptyset-\alpha))^2 + (Z + l_i cos(\emptyset-\alpha))^2)}\right]\}dl_i \quad (1)\ [6]$$

Now it can be seen that the equation is very complicated and could not be evaluated at any available mathematical software to obtain results easily and with lesser time. Moreover, it needs many input parameters and an approach to obtain them is not predictive in the equation.

III. COMPUTING MODELLING EQUATION

In order to evaluate the modeling equation (1), coding of a similar model which was developed by the author [7] is modified by making small changes. This is done by changing the functions $f, g, h, i, \& j$ to $f_1, g_1, h_1, i_1, \& j_1$ respectively. The changed functions are given as equation (2, 3, & 4).

$$f(l_i) = e^{-(X-l_i\sin(\emptyset-\alpha))\frac{V}{2a}}\{K_0\left[\frac{V}{2a}\sqrt{((X - l_i sin(\emptyset-\alpha))^2 + (z - l_i cos(\emptyset-\alpha))^2)}\right] \quad (2)$$

$$g(l_i) = e^{-(X-l_i\sin(\emptyset-\alpha))\frac{V}{2a}}\{K_0\left[\frac{V}{2a}\sqrt{((X - l_i sin(\emptyset-\alpha))^2 + (z + l_i cos(\emptyset-\alpha))^2)}\right] \quad (3)$$

$$h(w_i) = 0 = i(w_i) = j(w_i) \quad (4) \quad [6]$$

The modified coding can be used to calculate temperature rise distribution at various points of chip due to primary deformation zone; for any combination of tool and work piece combination; for dry turning operation and for any combination of machining parameters.

IV. VALIDATION OF PROGRAM

Komanduri and Hou [6] used input parameters of Loewen & Shaw [8] (table 1) for his modeling equation (1) to develop temperature rise contour graph at various points of chip due to primary heat source (Fig.1). Developed coding is tested using same input parameters and the generated contour graph is shown in Fig. 2.

Table 1: Cutting data for machining steel from Loewen & Shaw [8]

Work material	SAE B1113 steel
Tool	K2S carbide 20°rake, 5° clearance
Cutting Velocity	232 cm/sec.
Depth of cut	0.006
Width of Cut	0.384 cm
Chip Contact Length	0.023 cm
Main Cutting Force	356 N
Feed Force	125N
Passive Force	0 N
Chip Thickness Ratio	0.51
Thermal Diffusivity	0.1484 sq.cm/sec.
Thermal Conductivity	0.567 Watt/cm deg. cel.
Range of X co-ordinate	-150 to 50 µm
Range of Z co-ordinate	-200 to 0 µm

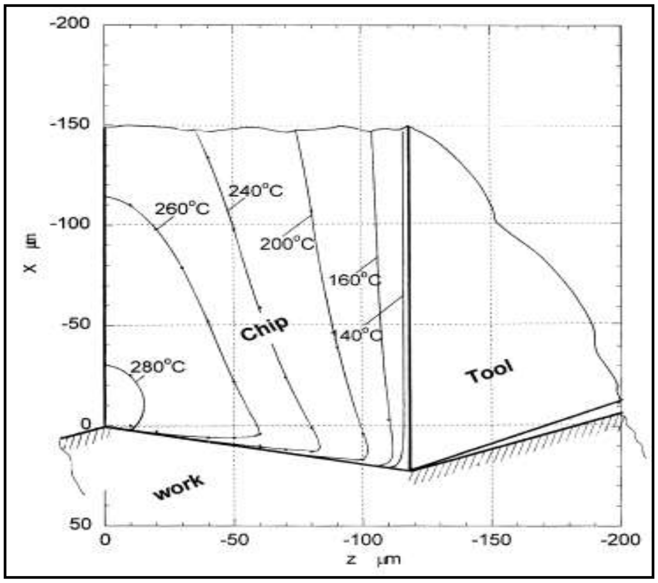

Fig. 1: Temperature rise contours at various points of chip due to primary deformation zone obtained by Komanduri and Hou by using input parameters of Table 1 [6]

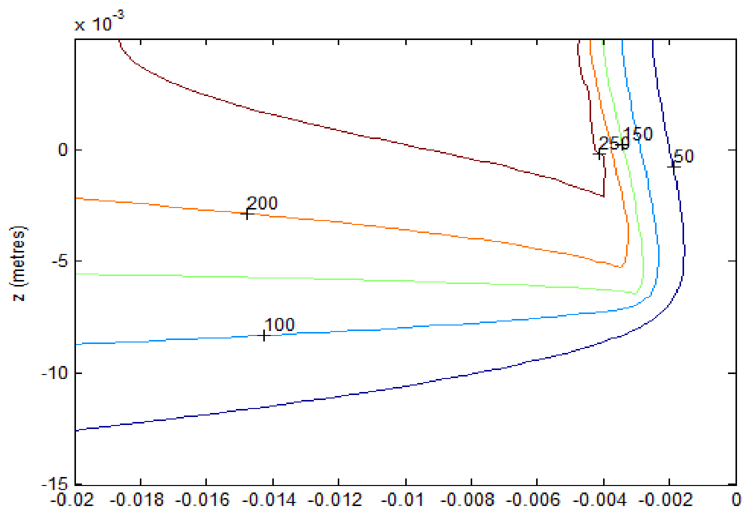

Fig. 2: Temperature rise contours at various points of chip due to primary deformation zone by using input parameters of Table 1 and developed MATLAB program

Comparing fig.1 and fig.2, it is observed that output results of both the approaches matches almost close to each other (difference of 17 °C in maximum temperature rise value; maximum value at actual display of results at MATLAB® screen is 263 °C, graph shows contour lines with same difference in temperature rise values). Therefore program can be considered for validation.

V. Mathematical Computation of Temperature Rise Distribution at EN31 Steel

This section deals with mathematical evaluation of temperature rise distribution at EN31 Steel chip when machined with CVD coated carbide insert. It comprises of two sub sections comprising of experimental setup, methodology & results.

A. *Experimental Setup*

In order to carry out machining action, Digital Read Out pioneer -175 machine is used for machining EN31 Steel (reinforced material composition is given in table 2) with MTCVD coated carbide insert (ISO number CCMT 09 T3 04-PM 1515). In order to measure generated forces (cutting force, feed force & axial force), DKM2010 turning dynamometer is attached to the lathe machine. It can measure forces up to 2000 N with a resolution of 0.1%. For measuring chip thickness Digital Vernier Caliper is used. The entire setup is shown in fig. 3.

Table 2: Reinforcement composition of EN31 Steel under study

C%	Mn%	Si%	S%	P%	Cr%	Ni%	Mo%
1.03	0.45	0.328	<0.005	<0.008	1.5	<0.05	0.059

B. *Methodology & Results:*

The purpose of the study is also to analyze influence of cutting parameters on developed machining forces and maximum temperature rise at EN31 Steel chip when work piece is turned with MTCVD coated carbide insert. For this, three values of cutting speed, feed rate and depth of cut each are selected as given in table 3.

Table 3: Various values of cutting parameters selected for machining

Cutting Parameters	**Value 1**	**Value 2**	**Value 3**
Velocity (rpm)	224	320	508
Feed rate (cm/rev)	0.008	0.015	0.022
Depth of Cut (cm)	0.025	0.050	0.075

In order to carry out further work, all combinations of cutting parameters are generated and 24 combinations are used for machining to generate forces and chip thickness. Rake angle of the tool insert is 7°, and thermal conductivity & thermal diffusivity of work material is 0.433W/s °C and 0.1172cm^2/s respectively. These values are taken from standard data books. These generated input parameters all together are applied on developed coding to generate temperature rise contour graphs with respect to various co-ordinates of chip. Some of the developed graphs are shown in figs (4, 5, and 6).

After generating the graphs, peak temperature rise is notified for each experiment from the respective contour graph and a table is prepared for analysis as shown in table 4.

From table 4, it can be seen that with increase in cutting velocity, feed rate and depth of cut; developed forces and maximum temperature rise increases. Cutting velocity plays big role in increasing these values (see experimental results 1-24). After cutting velocity, feed rate is responsible (see experimental results (6,9, 12, 21,24), (1,7,10, 16,17,19,20,22,23), (2,5,15)) followed by Depth of Cut (DOC) which plays least role in increasing the values of developed forces and maximum temperature rise at chip (see experimental results (8, 11, 14), (3, 6), (7, 10)).

VI. CONCLUSION

By using the coding; industries can estimate temperature rise at various points of chip due to shear plane for any machining parameters during operation itself and thus reducing planning and idle time. Also, MATLAB software is cheap & readily available. It can also be concluded that with increase in cutting parameters, developed forces and temperature rise at chip side due to shear plane increases. Cutting velocity plays major role in varying these values and increase in depth of cut has least effect in comparison to all cutting parameters for fluctuating these output values.

VII. FUTURE SCOPE

1. The MATLAB coding developed in the work can be used to calculate thermal stresses developed during machining at various points of chip due to shear plane.

2. The coding can be modified for other simple operations (like facing) and complicated processes (like milling, grinding, drilling etc.)

Fig.3. Experimental Setup - DRO pioneer -175 with DKM2000 dynamometer

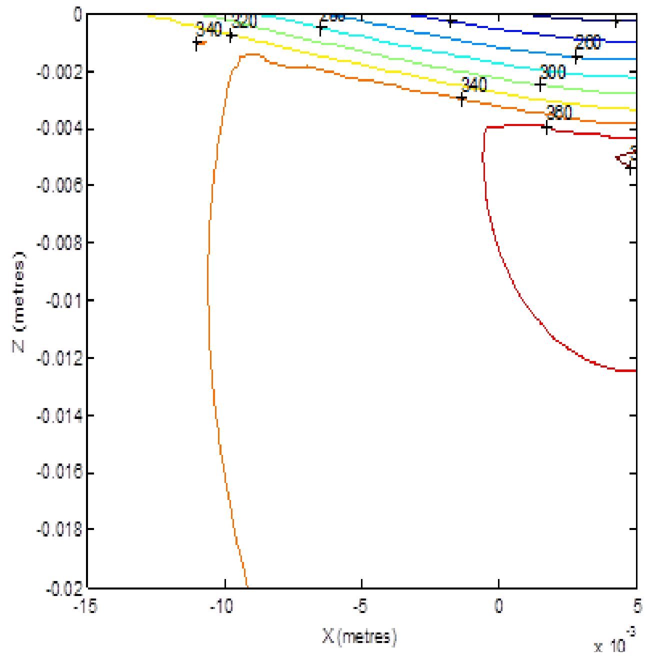

Fig. 4: Temperature rise contour graph developed by MATLAB coding for V_c = 51.111 cm/s, f = 0.008 cm/rev, and DOC = 0.05 cm

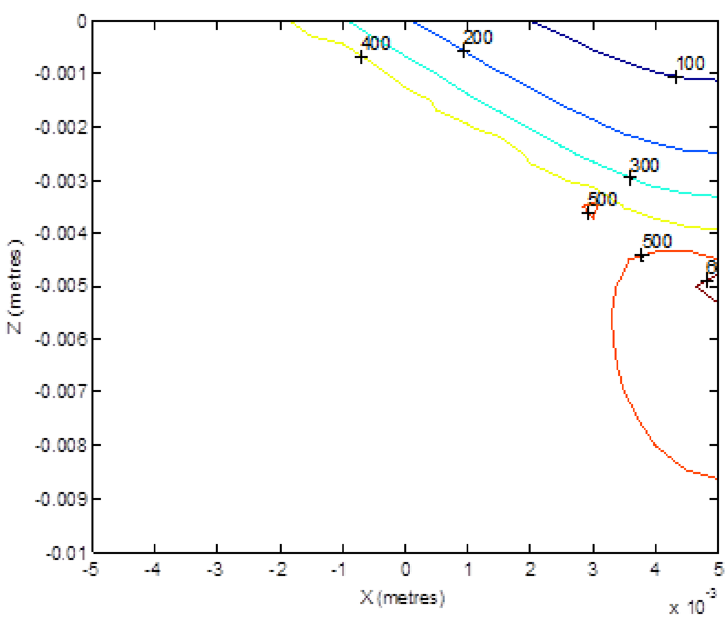

Fig. 5: Temperature rise contour graph developed by MATLAB coding for V_c = 113.519 cm/s, f = 0.008 cm/rev, and DOC = 0.075 cm

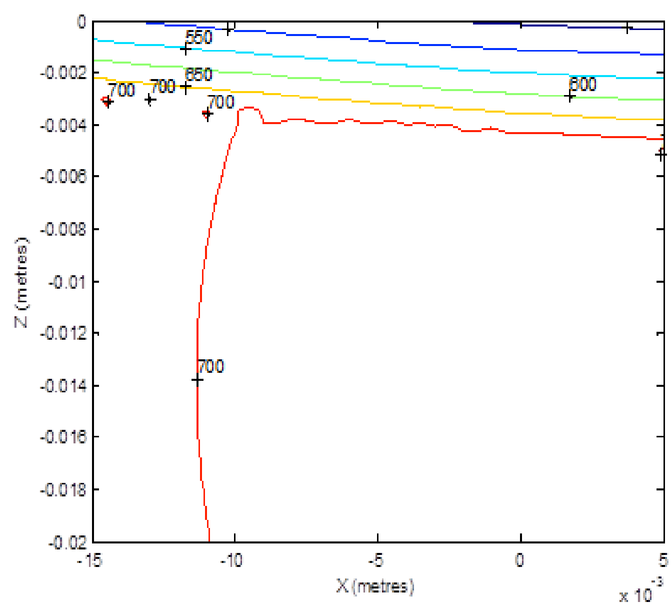

Fig. 6: Temperature rise contour graph developed by MATLAB coding for V_c = 58.111 cm/s, f = 0.022 cm/rev, and DOC = 0.05 cm

Table 4: Input data and temperature results for equation (1)

S.No.	**Dia**	**Cutting Parameters**				**Vernier Reading**	**Forces**			**Peak Temperature**
		Chuck Speed	V_c	**w**	**DOC**	**Chip Thickness**	F_c	F_f	F_r	$\theta_{chip\_primary}$
	cm	**rpm**	**cm/s**	**cm/rev**	**Cm**	**cm**	**N**	**N**	**N**	**Deg. Cel.**
1	4.36	224	51.111	0.008	0.05	0.08	121	72	21	361
2	4.39	320	73.518	0.008	0.05	0.07	210	110	41	452
3	4.36	508	115.912	0.008	0.05	0.1	276	167	69	600
4	4.27	224	50.056	0.008	0.075	0.09	123	76	22	357
5	4.27	320	71.508	0.008	0.075	0.089	311	127	45	485
6	4.27	508	113.519	0.008	0.075	0.088	347	166	97	601
7	3.96	224	46.422	0.015	0.025	0.066	142	83	33	380
8	3.96	320	66.317	0.015	0.025	0.076	222	132	47	315
9	3.96	508	105.278	0.015	0.025	0.145	427	184	77	622
10	3.72	224	43.608	0.015	0.05	0.069	151	91	35	387
11	3.85	320	64.475	0.015	0.05	0.073	299	141	59	320
12	3.94	508	104.746	0.015	0.05	0.107	452	205	102	631
13	3.45	224	40.443	0.015	0.075	0.096	299	118	61	240
14	3.23	320	54.092	0.015	0.075	0.098	356	114	77	300
15	3.1	508	82.415	0.015	0.075	0.089	407	141	56	519
16	3.73	224	43.726	0.022	0.025	0.083	325	147	67	650
17	3.5	320	58.613	0.022	0.025	0.109	358	151	73	700
18	2.93	508	77.895	0.022	0.025	0.121	392	161	63	631
19	3.73	224	43.726	0.022	0.05	0.088	393	174	96	671
20	3.47	320	58.111	0.022	0.05	0.096	402	185	128	719
21	3.87	508	102.885	0.022	0.05	0.109	625	391	141	703
22	3.62	224	42.436	0.022	0.075	0.088	399	176	124	699
23	3.4	320	56.939	0.022	0.075	0.098	421	183	132	732
24	3.74	508	99.429	0.022	0.075	0.103	631	394	177	709

3. Though the study is done considering primary deformation zone, MATLAB coding should also be done for secondary deformation zone.

4. The coding can be used to determine optimum cutting parameters for a particular tool-work combination. This can be done using optimization software like RSM, ANN, Taguchi method etc.

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APPENDIX

Abbreviations	Details	Source	Unit
$\theta_{chip-primary}$	Temperature rise at chip due to primary deformation zone	Refer equation (1)	°C
α	Rake angle	Tool specifications	Degree
t_c	Undeformed chip thickness	= depth of cut (DOC)	Cm
t_{chip}	Deformed chip thickness	Digital Vernier Caliper	Cm
r	Chip thickness ratio	t_c/t_{chip}	--
$\emptyset$	Shear angle	$tan^{-}\frac{r\,cos\propto}{1-r\,sin\propto}$	Degree
w	Width of chip	= feed rate	Cm
X, Z	X and Z co-ordinate at which temperature rise is to be calculated	---	µm
F_c	Cutting force	Experimental (dynamometer)	N
F_f	Feed force	Experimental (dynamometer)	N
F_r	Radial force	Experimental (dynamometer)	N
F_{xy}	Resultant of feed force and radial force	$\sqrt{(F_f^2 + F_r^2)}$	N
F_s	Shear force	$F_c cos\emptyset - F_{xy} sin\emptyset$	N
V_c	Cutting velocity	Input Cutting Parameter	cm/s
V_s	Shear velocity	$\frac{V_c\,cos\propto}{cos(\emptyset-\propto)}$	cm/s
L_{ab}	Length of shear plane	$t_c/sin\emptyset$ or $t_{chip}/cos(\emptyset-\alpha)$	Cm
k	Thermal conductivity of chip	Data book	J/cms°C
a	Thermal diffusivity of chip	Data book	cm²/s
q_{shear}	Heat intensity of the primary heat source	$\frac{F_s V_s}{L_{AB} w}$	J/cm²s