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In-Situ Tool Performance Evaluation in Drilling using Infrared Thermography

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Abstract

Most of the drills used today are manufactured from solid carbide primarily due to their high power, which is important for the intermittent drilling cutting action. A significant explanation for the incidence of damage is accelerated wear of the instrument due to the abrasive workpiece materials. This results in repeated modifications of the drill that impact the manufacturing cycle and increase the final cost. Drill geometry is an important aspect that defines the consistency of the hole being drilled. This paper focuses of characterizing the drill tool performance using real time tool condition monitoring (TCM). Recommendations are given to assist in the selection of the appropriate drill for the desired criterion of hole quality by clearly focuses on the relationship between the diameter of the drills and the tool temperature in drilling of IS3048 steel.

Key words:Tool Temperature; Tool Life; FLIR; Drilling Operations

1. Introduction

Heat cutting is a basic physical phenomenon of machining which induces elevated temperatures in the local cutting zone [1], resulting in many severe issues, including unnecessary tool wear [2], reduced tool life [3] and poor machining precision. Drilling plays an important role in the machining process [4], and is widely recommended for thoroughly finished products. During the machining operation, enormous quantities of heat [5] are produced due to the extreme friction in the cutting zone [6] induced by metal deformation. The resultant extreme temperature [7] eventually worsens the wear of the instrument and cuts its life, although at the similar time impairing the integrity of the surface and the quality of the process. Evidently, it is important to study the temperature of the cutting tool [8] in order to increase the cutting condition [9] of the drilling process. The true friction status of the tool-chip interface and the temperature drop step are not regarded in these experiments, resulted in the inaccuracy of the cutting temperature forecasts. As a result, the machining of materials such as steel encountered high temperatures [10] which caused rapid tool wear due to the abrasion produced during machining. A hybrid experimental, theoretical and numerical method was used to analyze the temperature of the cutting tool. This paper reflects on the model of tool life by analyzing the temperatures in the drilling process.

2. Materials and Methods

In-situ condition monitoring keeps on acquiring interest inside the manufacturing space as new and quicker sensors are being developed. However, the plan of tool monitoring framework for diminished intricacy and expanded robustness has been infrequently considered. Accordingly, present work focuses on TCM while machining IS3048 steel using solid carbide drills as shown in Table 2. IS3048 Steel specimens of size (150x150x10mm) are used as work materials, chemical composition and mechanical properties is given in Table 1.

Table 1: Chemical Composition and Mechanical Properties of IS3048 Workpiece

Chemical Composition		Mechanical Properties	
Ni	80.00~10.50	Hardness (Hv)	70
Cr	18.0~20.0	Elongation(%)	40
C	0.08	Tensile strength(M/mm^2)	520
		Yield strength (N/mm^2)	205

An FLIR E60 infrared thermal camera placed at a distance of 8 feet far away from the tool which is utilized to record the cutting temperatures at the same time as cutting velocity and feed rate changed. Examinations were done on CNC vertical machining focus as displayed in Figure 1, by varying the spindle speeds between 600 and 1200 rpm.

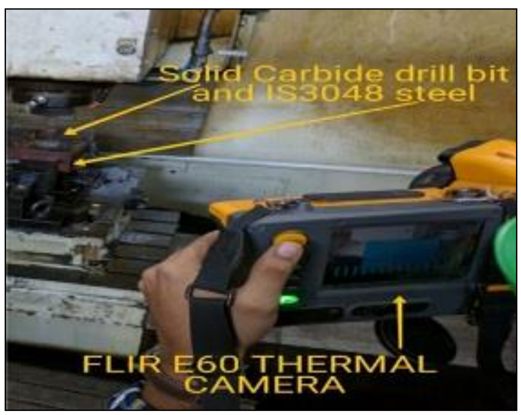

Fig. 1 Experimental Setup in Drilling of IS3048 Steel

The machining is carried out under controlled conditions using varied 7 mm and 3 mm solid carbide drills as given in Table 2. During machining process, the FLIR E60 Imager is focused. High resolution thermal images are recoded for every pulse interval. The experiments were conducted based on the orthogonal L9.

Table 2. Tool Specifications.

Parameters	Tool A (mm)	Tool B (mm)
Diameter	Ø7mm	Ø3mm
Shank Diameter	8 mm	5 mm

Cutting Edge length	38 mm	38 mm
Overall Length	165 mm	100 mm

From the experiments, the results obtained are plotted as shown in Table 3 and 4.

3. Results and Discussion

The results were plotted based on the investigation in acquiring data during the experimentation and the findings for the relatively Tool A and Tool B is analyzed.

3.1 Thermography Analysis

Each test condition designed with L9 orthogonal array method. The results are tabulated as shown in Table 3. The drilling operation is carried out on an IS3048 steel having 150x150x10mm with of 7 mm diameter and 3 mm diameter solid carbide drill tools. The thermography analysis is performed during the drilling process by recording the temperature and generating high resolution images. A set of two reading have been recorded for accuracy for each test condition (TC1, TC2, …TC9) performed on each tool.

Table 3 Tool AØ7mm Diameter.

Test condition	Feed rate (f) mm/rev	Rotational speed (N)	Depth of cut, d	Initial Temperature, T1	Final Temperature, T2	Mean Temperature, T_a
TC1	0.5	600	8	173.5	170.6	172.05
TC2	0.1	600	10	178	176	177
TC3	0.2	600	12	185	183	184
TC4	0.5	900	10	192	190	191
TC5	0.1	900	12	195	193	194
TC6	0.2	900	8	180	179	179.5
TC7	0.5	1200	12	183	182.6	182.8
TC8	0.1	1200	8	179	180.5	179.75
TC9	0.2	1200	10	177	178.9	177.95

Table 3 clearly shows the temperature measured using FLIR E60 Thermal image non-contact temperature sensing device. The initial temperature (T1) and final temperature (T2) are recorded. The mean temperature (T_a) of the initial and final temperature readings is noted for each test condition. Similarly, the temperature readings for the test conditions performed by the Tool B with 3mm diameter solid carbide tool are measured and recorded which is tabulated as shown in Table 4.

Table 4. Tool BØ3mm Diameter.

Test conditions	Feed rate (f)	Rotational speed (N)	Depth of cut, d	Initial Temperature, T1	Final Temperature, T2	Mean Temperature, Tb
TC1	0.5	600	8	159	157	158
TC2	0.1	600	10	159.5	157.6	158.55
TC3	0.2	600	12	161	159	160
TC4	0.5	900	10	162.6	161	161.8
TC5	0.1	900	12	166.1	164.2	165.15
TC6	0.2	900	8	161.6	160	160.8
TC7	0.5	1200	12	159.8	157	158.4
TC8	0.1	1200	8	158	161	159.5
TC9	0.2	1200	10	160.3	158	159.15

The following are the thermographic images captured while the drilling operation with being done with the 7 mm diameter solid carbide tool. The test condition analysis of the solid carbide tools used for the machining is carried out as shown in Figure 2. The thermal image recorded for test conditions are shown in the Figure 2 to 7, for Tool A and Tool B.

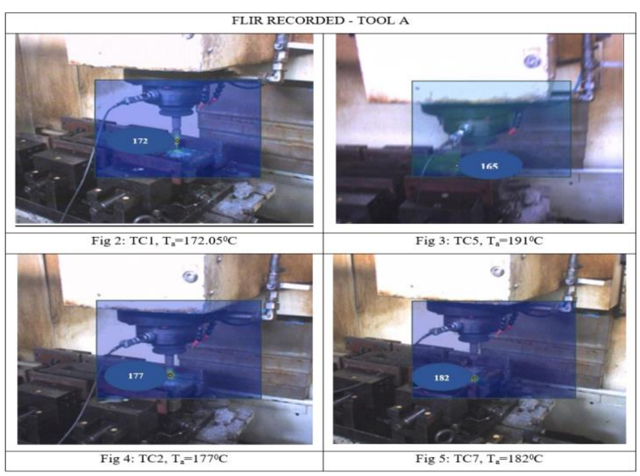

Fig 2: TC1, T_a=172.05°C

Fig 3: TC5, T_a=191°C

Fig 4: TC2, T_a=177°C

Fig 5: TC7, T_a=182°C

SFigure 2 to 5 clearly shows the thermal conditions recorded at various test conditions of Tool A during drilling process. Figures 2 and 3 shows measured temperatures at test conditions of TC1 and TC5 where at TC1 the temperature is at 172.05^{0}C and at TC5 the temperature is 195^{0}C for the Tool A with 7mm diameter. From the analysis it can clearly understand that the temperatures tend to raise with increase cutting conditions along with speed, feed and depth of cut. Whereas, at test conditions of TC2 and TC7 the temperatures recorder is 177^{0}C and 182^{0}C as shown in Figure 4 and Figure 5 which can clearly define the increase in temperature with increase in tool diameter and cutting conditions which are given in Table 3.

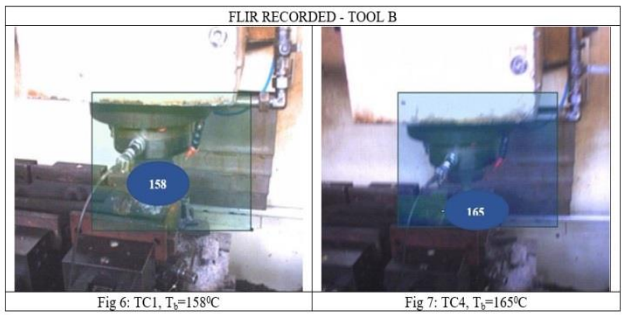

Fig 6: TC1, T_b=158^{0}C

Fig 7: TC4, T_b=165^{0}C

Similarly, for Tool B, Figures 6 and 7, clearly shows measured temperatures at test conditions of TC1 and TC4 where at TC1 the temperature is at 158^{0}C and at TC4 the temperature is 165^{0}C for the Tool B with 3mm diameter. From the analysis it can clearly understand that the temperatures tend to raise with increase cutting conditions along with speed, feed and depth of cut. So as to clearly understand the Tool A temperature analysis with respect to the Tool B, the recoded data is observed for better understanding as plotted in the graphs shown in Figure 8 and 9.

3.2Temperature Analysis in Tool A

From the recorded reading from the Table 3 for Tool A, the graph is plotted shown in Figure 8. The temperature tends to raise with increase speed at TC5 where reading is noted to be 194^{0}C at feed rate (f) is 0.5mm, rotational speed (N) is 900 and depth of cut (d) to be 12mm.

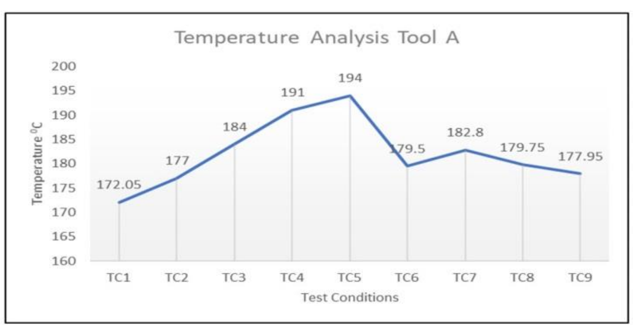

Figure 8: Temperature Analysis of Tool A

From the Figure 8, the lowest temperature reading is found to be at TC1 of 172^{0}C where it is the initial state of the tool performing the drilling operation. Since optimized parameters designed with L9

Orthogonal Array, the test condition TC5 showed highest temperature condition during drilling process.

3.3 Temperature Analysis in Tool B

From the recorded reading from the Table 4 for Tool B, the graph is plotted shown in Figure 9. The temperature tends to raise with increase speed at TC5 where reading is noted to be 165^0C at feed rate (f) is 0.5mm, rotational speed (N) is 900 and depth of cut (d) to be 12mm.

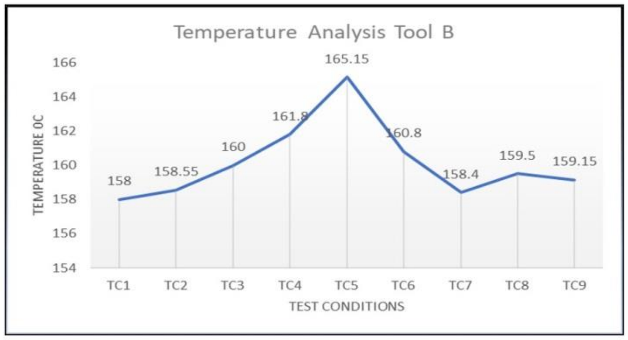

Figure 9: Temperature Analysis of Tool B

From the Figure 9, the lowest temperature reading is found to be at TC1 of 172^0C where it is the initial state of the tool performing the drilling operation. Since optimized parameters designed with L9 Orthogonal Array, the test condition TC5 showed highest temperature condition during drilling process. The temperatures measured is for the tool with 3mm diameter.

3.4 Comparative Temperature Analysis

When compared the temperature of the Tool A is significantly increased than Tool B which is as shown in Figure 10. The temperatures of the Tool A with 7mm diameters are observed high than 3mm diameter since the contact of the tool tip with workpiece is less developing less friction that higher diameter.

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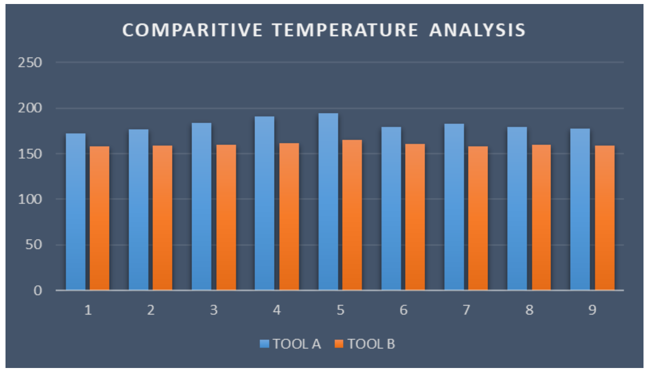

Fig. 10 Compartive Temperature Analysis of Tool A and Tool B

From Figure 10, the highest temperature is measured for both the tools at test conditions TC5 recording 165 ^{0}C and 161 ^{0}C where speed (N) having 900 rpm, feed (f) 0.5mm and depth of cut 12mm. Similarly, the initial temperatures measured for both the tools are at test condition TC1. From the investigation the maximum temperature is observed at TC5 for Tool A having 7mm diameter than that of Tool B which is having lesser diameter of 3mm.

3.5 Mathematical Models of Cutting Temperature

The amount of heat generated during metal removal process affects the cutting process and tool state which are dependent on feed, depth of cut and speed. The prevailing cutting conditions varying tool diameters show high affect in resulting in tool damage. In order to calibrate the tool temperatures, using the linear regression technique the following linear model resulted which is as shown in the Eq. (1),

$$\Delta T = —46.38 \text{ -l- } 0.216\, t + 5.62\, d + 20.12\, F + 0.0081\, V + 0.023\, D (^0C) \quad (1)$$

Statistical results show, $R^2 = 0.97$.

Adjusted $R^2 = 0.91$.

Standard Error (SE) = 5.26.

Where, ΔT indicates the raise in temperature after t minutes cutting (^{0}C), V, d and F are the speed, feed and depth of cut respectively and D indicates the tool diameter in mm. The linear model shows the temperature raise in the tools is optimized and affected positively by: tool diameter, cutting conditions with respect to speed, feed and depth of cut. The effect of cutting conditions varying tool diameters results in affecting cutting temperatures.

4. Conclusions

Assurance of the heat segment (into the cutting apparatus and the chip during cutting) and temperature dispersion along the rake face of the cutting tool is of specific significance as a result of its controlling effect on cutting tool life, just as, the nature of the machined part. From the experimental investigations it was clear that the tool with high diameter is found to generate more than lesser one.

The temperature is found to be higher in Tool A than Tool B which is caused by the higher abrasive contact zone. Whereas, in the design of experiments, it is also observed that the temperature tends to increase at TC5 with speed having speed (N) of 900rpm, feed rate (f) having 0.1mm and Depth of Cut (d) as 12mm in both the cutting tools. The temperature with regularized optimized cutting conditions showed enormous affect in tool condition. An investigation has been done on the impact of cutting conditions as cutting speed, feed and cutting depth on the temperature circulation along the contact zone varying tool diameters.

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