Journal of Materials Science & Surface Engineering, 5(4): 593-596
ISSN (Online): 2348-8956; 10.jmsse/2348-8956/5-4.4

Investigation of effects of Thermal assisted machining process on EN 19 steel

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ABSTRACT

Super alloys are introduced in these days in industrial environment for better strength applications. It is widely understood that aerospace materials such as titanium, nickel based alloys and high strength steels are difficult to machine inspite of their material properties. Previous research in concerned area indicates that an alternative pathway to achieve greater tool life is thermally assisted machining (TAM). This approach is seemingly contradictory to the traditional method and instead relies on introducing heat from an external source to reduce the work piece material's strength and hardness, thereby reducing cutting forces and making the material easier to machine. The objective of present work is to investigate the role of thermal assisted machining; especially plasma assisted machining on various parameters at optimal speed, feed and depth of cut, and to compare the effectiveness of dry machining with thermal assisted machining on EN-19 steel. The results reveal the significantly enhanced output values when compared to dry machining in terms of surface roughness, Micro-hardness, and chip reduction coefficient.

ARTICLE HISTORY
Received 30-03-2017
Revised 01-06-2017
Accepted 05-06-2017
Published 29-06-2017

KEYWORDS
Non-conventional machining,
Thermal assisted machining,
EN19 steel

Introduction

Machining of many aerospace components is difficult due to their thermo-mechanical properties. For example, machining of titanium alloys is highly sluggish and slow in the order of eight to ten times compared with aluminum machining[1]. Difficult-to-machine materials include most ceramics and selected alloys and composites[2]EN19 also known as 709M40 is a high quality alloy steel, renowned for its good ductility and shock resistant and its resistance to wear properties. It is suitable for gears, pinions, shafts, spindles,; it is now also widely used in the oil and gas industry[3]. The diesel engine camshafts are generally made by EN19 Steel material. However, EN19 steel material has low wear resistance and its service life is shorter [4]. Since the resistance to wear of EN 19 steel is very high, it is always difficult to machine such hard materials. Workpiece temperature plays an important role in the chip formation during the metal cutting process as it affects the material deformation. The large amount of energy generated due to the bulk deformation and friction is almost exclusively converted to thermal energy, leading to high chip and tool cutting temperatures. This thermal energy help to cut the material by soften the workpiece. The concept of thermally assisted machining is based on same. During TAM, the workpiece material is locally heated and softened and then removed by a conventional cutting tool. In thermal assisted machining consists of heating the work-piece, either by plasma arc, with the help of laser and other heating source. TAM improves the machinability of titanium alloys though a reduction in cutting forces, typically reported between 15% to 50% [2]. TAM shows that 80% of the flank wear and 60% of the crater wear have been reduced [3]. Laser Assisted Machining (*LAM*) of Inconel 718 reported a reduction of tool wear by 40%, cutting force by 18% and increase in metal removal rate by 33% [4]. The technique has been also found economically beneficial as compared to conventional machining [7, 8]. Many studies reveal the positive effect of TAM. Ahn, Woo, & Lee, 2016[5] used a hybrid machining approach, laser assisted machining (LAM) and improved productivity and surface quality, in which the workpiece is softened by laser preheating. Hwang, Oh, & Lee, 2016[6]in this study, three preheating methods, one-way, zig-zag, and back-and-forth, are proposed for machining silicon nitride using laser-assisted milling. M. J. Bermingham, et. al, 2015)[7] compared the tool life during laser assisted milling, dry milling, milling with flood emulsion, milling with minimum quantity lubrication (MQL) and a hybrid laser + MQL process. Nurul Amin et al., 2013[8]-The authors of the current research have therefore looked into the application of a simple Tungsten Inert Gas (TIG) welding setup to perform heat assisted turning of AISI 304 Stainless Steel. Amin, Hossain, & Patwari, 2011[9] conducted a study on heat assisted end milling of Inconel 718 using inducting heating technique to enhance the machinability of the material. Masood, Armitage, & Brandt, 2011[10] studied laser-assisted machining of hard-to-wear white cast iron. Machining of some materials such as high chromium alloys and high strength steels was challenging task and had received little attention. Baili, Wagner, Dessein, Sallaberry, & Lallement, 2011[11] investigated the hot machining with induction to improve Ti-5553 machinability. Germain, Dal Santo, & Lebrun, 2011[12] investigated and concluded that the cutting force can be decreased, by as much as 40%, for various materials. Pfefferkorn, Lei, Jeon, & Haddad, 2009[13] studied the flow of energy in TAM in an attempt to determine how beneficial preheating is? Anderson et al., 2006[14] economically analyzed Laser-assisted machining of Inconel 718. The machinability of Inconel 718 under varying conditions was evaluated by examining tool wear, forces, surface roughness, and specific cutting energy. Ezugwu, 2005[15] investigated the behavior of engineering materials when machining at higher cutting conditions from practical and theoretical standpoints. Rebro, Shin, & Incropera, 2004[16] investigated design of operating conditions for crack-free laser-assisted machining of mullite.

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Experimental

Materials

The material of work-piece is EN-19 steel. EN-19 is selected because it is used for manufacturing of medium size components like machine tools, pinions, spindles, gears and shafts etc which are important product of mechanical industry. Table 1 shows the composition of EN 19 steel.

Table 1: Chemical composition of EN 19 steel

Elements	Per. %
Carbon	0.36 - 0.44
Silicon	0.10 - 0.35
Manganese	0.70 - 1.00
Chromium	0.90 - 1.20
Molybdenum	0.25 - 0.35
Sulphur	0.035 max
Phosphorus	0.040 max

Selection of Tool

Tungsten carbide insert (CNMG120408) used in present work, Carbide cutting tools' edges are of carbide tips which are brazed onto steel bodies. This means they have higher levels of resistance to wear, and they can have a long working life.

Experimentation

Three factors and three levels have been selected respectively for experimentation from the taguchi's standard orthogonal table, L9 array is selected for design the experimentation. A total of 18 experiments based on Taguchi's L9 orthogonal array will be carried out with different combinations of the levels of the input parameters. Figure 1 shows the drawing of the workpiece.

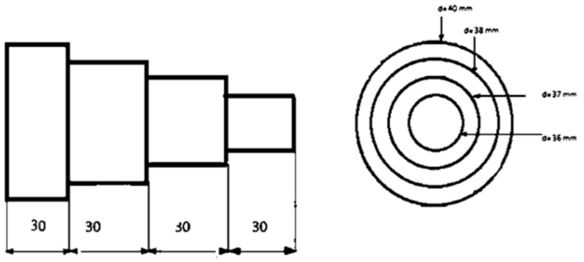

Figure 1: Drawing of the work-piece

Preparation of Setup

In the present research introduction of the heat to cutting zone is done by a Butane torch, due to its ease of availability as compared to costly laser and plasma techniques. Since the laser process is most widely used for thermal assisted machining, but due to its high cost and unavailability, the heat was introduced by plasma. Schematic diagram of Experimental set-up is shown in Fig. 2. It consists of a butane torch, and flow control valve. The construction of an experimental set up is given below.

The work has been performed on a lathe machine at Guru Nanak industries, Industrial area Ludhiana. The spindle speed for the machine ranges from the 44 rpm to the 1000 rpm. The depth of cut ranges from 0.2 mm to 3.6 mm and the range of feed on the machine is from 0.05 mm/rev to 1 mm/rev. The control-unit which consists of the levers to set the spindle speed and feed for the various combinations for experimentation. Step turning operation was performed on each piece over the length of 30 mm per step into three steps. A plasma torch was used to introduce the heat to work-piece. The workpiece were also preheated for 15 min.

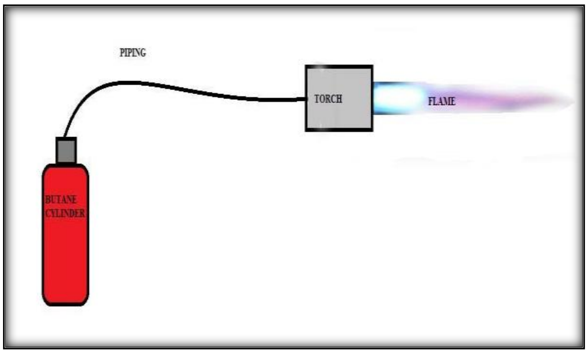

Figure 2: Thermal assisted machining set up

Machining of Samples

After machine preparation and setup making the samples will be machined on lathe. The parameters considered for this study have been summarized in Table 2. The Combinations of these parameters are selected as the tool recommendations.

Table 2: Levels of input parameters

Sr. no.	Input parameter	Level 1	Level 2	Level 3	Units
1	Feed rate	0.05	0.10	0.15	mm/min
2	Cutting velocity	110	86	59	m/min
3	Depth of cut	0.5	1	1.5	mm

Testing and Analysis

After machining, the following machining Properties of samples were prepared and tested to analyze the performance of thermal assisted machining compared to dry machining. The influence of each parameter has been reported accordingly on the output response. Following are the output parameters which have been selected for optimum conclusion and justification of machining. These output parameters are:

- Micro-hardness
- Chip-reduction co-efficient
- Surface roughness

Results and Discussion

Influence of various input parameters on Chip reduction co-efficient

Chip reduction coefficient (ζ) is defined as the ratio of chip thickness (S1) to the uncut chip thickness (S). This factor, ζ, is an index of the degree of deformation involved in chip formation process during which the thickness of layer increases and the length shrinks. Observations for TAM and Dry machining environments of chip reduction coefficient are listed in Table 3. Chip reduction coefficient was calculated as

$$\textit{Chip reduction coefficient} = \textit{chip thickness} / \textit{depth of cut} \tag{1}$$

Table 3: Observations for TAM and Dry machining environments of chip reduction coefficient

Run	Machining Environment	Cutting velocity (m/min)	Feed Rate (mm/rev)	Depth o cut	Chip Reduction Coefficient (ξ)
1	Dry	110	0.05	0.5	0.93
2	Dry	110	0.10	1	0.89
3	Dry	110	0.15	1.5	0.85
4	Dry	86	0.10	0.5	0.94
5	Dry	86	0.15	1	0.91
6	Dry	86	0.05	1.5	0.80
7	Dry	59	0.15	0.5	0.95
8	Dry	59	0.05	1	0.87
9	Dry	59	0.10	1.5	0.81
10	TAM	110	0.05	0.5	0.95
11	TAM	110	0.10	1	0.92
12	TAM	110	0.15	1.5	0.87
13	TAM	86	0.10	0.5	0.96
14	TAM	86	0.15	1	0.94
15	TAM	86	0.05	1.5	0.82
16	TAM	59	0.15	0.5	0.98
17	TAM	59	0.05	1	0.90
18	TAM	59	0.10	1.5	0.83

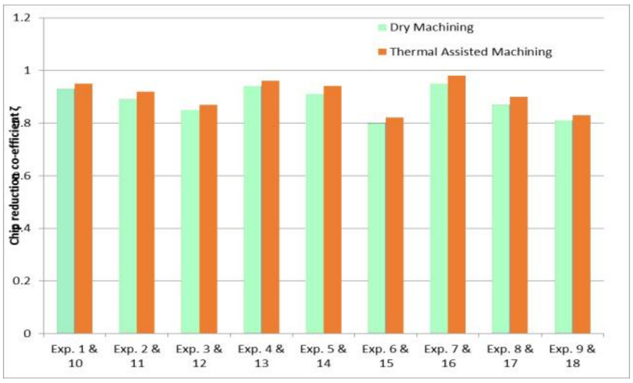

Figure 3: Effect of various parameters on chip reduction coefficient in TAM and dry machining

Figure 3 shows the influence of various input parameters on chip reduction co-efficient during the dry machining environment. The graphs have been plotted by considering the observation tables 3. The graphs reveal the effect of the dry machining environments on chip reduction co-efficient. As the graphs clearly reveal that chip reduction co-efficient has increased in TAM, due to the softening of material by the application of heat, chip thickness has increased, hence the chip reduction co-efficient.

Influence of various input parameters on Surface roughness (Ra)

Observation Table 4 shows the results of surface roughness. Three readings on each experimental workpiece were taken and out of which mean is taken to reduce the error.

Figure 4 shows the graphical representation of results of surface roughness in dry and TAM working conditions. It has been found that there is a slight decrease in surface roughness values in thermal assisted machining as compared to dry machining. This is due to the softening of material with the application of heat, which causes the material to cut easily, causing a good surface finish. Hence TAM machining could help decreasing the roughness of the work material upto some extent.

Table 4: Observations for surface roughness

Run	Machining Environment	Cutting velocity (m/min)	Feed Rate (mm/rev)	Depth o cut	Surface roughness (Ra)
1	Dry	110	0.05	0.5	1.11
2	Dry	110	0.10	1	1.13
3	Dry	110	0.15	1.5	1.21
4	Dry	86	0.10	0.5	1.26
5	Dry	86	0.15	1	1.29
6	Dry	86	0.05	1.5	1.22
7	Dry	59	0.15	0.5	1.49
8	Dry	59	0.05	1	1.23
9	Dry	59	0.10	1.5	1.35
10	TAM	110	0.05	0.5	0.96
11	TAM	110	0.10	1	1.01
12	TAM	110	0.15	1.5	1.08
13	TAM	86	0.10	0.5	1.16
14	TAM	86	0.15	1	1.09
15	TAM	86	0.05	1.5	1.14
16	TAM	59	0.15	0.5	1.3
17	TAM	59	0.05	1	1.17
18	TAM	59	0.10	1.5	1.26

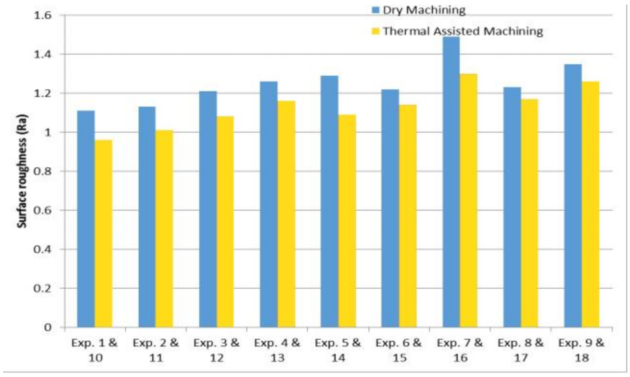

Figure 4: Effect of various parameters on surface roughness in TAM and dry machining

Influence of various input parameters on Micro-hardness (HV)

Observation Table 5 shows the results of Microhardness. Three readings on each experimental workpiece were taken and out of which mean is taken to reduce the error.

Figure 5 shows the graphical representation of effect of various parameters on micro-hardness in TAM and Dry machining. Since the application of heat was involved in the present work, it was expected that there would be some changes in micro-hardness of the work material. Since dry and TAM both are processed without the application of any coolant, there is always some change in micro-hardness of the work-piece. Results show that there is slightest increase in micro-hardness values in thermal assisted machining as compared to dry machining. Micro-hardness helps to resist wear, and is very useful property of the material. Thus it can be concluded that TAM process is useful to enhance the micro-hardness of the work material upto some extent.

Table 5: Observations for microhardness

Run	Machining Environment	Cutting velocity (m/min)	Feed Rate (mm/rev)	Depth o cut	Micro-hardness (Ra)
1	Dry	110	0.05	0.5	276
2	Dry	110	0.10	1	282
3	Dry	110	0.15	1.5	290
4	Dry	86	0.10	0.5	268
5	Dry	86	0.15	1	276
6	Dry	86	0.05	1.5	278
7	Dry	59	0.15	0.5	264
8	Dry	59	0.05	1	268
9	Dry	59	0.10	1.5	274
10	TAM	110	0.05	0.5	290
11	TAM	110	0.10	1	298
12	TAM	110	0.15	1.5	320
13	TAM	86	0.10	0.5	280
14	TAM	86	0.15	1	286
15	TAM	86	0.05	1.5	310
16	TAM	59	0.15	0.5	276
17	TAM	59	0.05	1	278
18	TAM	59	0.10	1.5	300

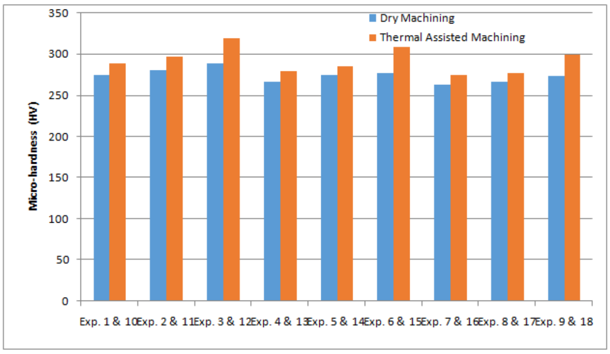

Figure 5: Effect of various parameters on micro-hardness in TAM and dry machining

Conclusions

Following conclusions can be made out of present research:-

1. It can be concluded from the present research that the thermal assisted machining is a viable alternative for the machining of hard to machine materials. Also it has been found that there is a slight improvement (2.12 % approx.) in chip reduction co-efficient as compared to dry machining. This is due to the reduction in cutting forces caused by softening of material, hence helping in the proper formation of chips.
2. It has also been found that there is increase in surface finish due to the thermal assisted machining process. The surface roughness has been decreased significantly when the machining was done with the assistance of heat. Approximately 13.5 % decrease in surface roughness has been found when TAM is applied. This is also due to the softening of material and reduction in cutting forces.
3. Microhardness values were expected to be increased as the work surface was introduced with heat. Heat always causes some degree changes in micro-hardness of the work material. Since the both dry and thermal assisted machining processes were known for heat generation, a slight increase (6.11 % approx.)in micro-hardness has been found, which is beneficial for material's wear resistance properties.

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