Specific Energy Based Characterization of Surface Integrity in Mechanical Machining

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Introduction

- Globally, manufacturing account for about 37% of the world total electrical energy demand generated in 2006 [1].
- Electrical energy demand is attributable to electricity generated from the use of fossil fuels which constitute and contributed to the world total CO_2 [2].
- Energy use and energy resources significantly influence the environmental impacts.
- In the course of converting coal to electricity, gases such as CO_2, SO_2, NO_2, etc, are emitted.

Introduction

- The manufacturing industry is one of the major sources of employment. Mechanical machining inclusive [2, 3].
- Environmental effect of manufacturing can be curtailed by increasing the energy efficiency of machine tools.
- Increased environmental impact of machine tools, led to its inclusion in the European Union’s ‘Energy Using Products’ directive [4].
- According to Kyoto Protocol; it is desirable that energy reduction be incorporated at the design stages for machine tools [5].
- In Africa, much control has not been achieved in terms of Global Warming Potentials GWP and mitigations.

Energy efficiency strategy of machine tools

- Recently, the issue of energy consumption has been of significant interest to manufacturers.
- This is because of the ever increasing energy costs as well as increased environmental impacts due to energy consumption.
- 65% of CO_2 emission is attributable to energy demand in the manufacturing sector [6].
- The IEA stressed on the importance of developing energy efficiency measures by 2050.

- The framework on energy saving measures for new products were proposed by the European Eco-design Directive 2005/32/EC [7].
- The sole aim of improving the energy efficiency through the embedded energy of the machine tool at the design stages.
- Standards such as the ISO 14955-1 ‘Environmental evaluation of machine tools’ [8], CECIMO ‘Self-Regulatory Initiative’ for energy-efficient machine tools [9], and CO2PE! [10] are all in agreement of such design proposal.

- Energy reduction at the process level for machining achieved through the optimization of the process parameters.
- it could be said that energy reduction through the optimization of the process parameters could affect the surface roughness and integrity of the machined component.
- The surface roughness therefore, is a trade-off between the energy reduction and the process mechanisms that should be further investigated since it is a determinant of the quality of the finished product.
- Hence it is required at this time to correlate the aesthetics (usually defined by the surface roughness) to electrical energy demand at the use phase.

- Machining operations generates waste resource. For example chips, scraps, used lubricants and coolants.
- These increase the environmental impacts of machining processes [3].
- The surface roughness value is governed by the cutting parameters and process variables.
- It was observed that varying the cutting parameters significantly reduced energy consumption [11, 12, 13] however the surface integrity of the machined components were not evaluated.

Surface roughness and specific energy trade-off: Issues of concern

- Surface roughness is a form of unevenness on the machined surface created by the combine movement of the cutting tool and the workpiece material [14].

- Affected by:
  - the machining parameters
  - dynamic properties of the cutting process
  - the cutting tool features
  - the workpiece characteristics [15-16],
  - machine tool configurations and toolpaths [16]

Research Context

- From the reviewed work, insight on the effects of toolpaths on energy demand has been provided by researchers.
- specific energy demand of machined components has not been correlated with the surface roughness obtained.
- to improve energy efficiency in mechanical machining, it is important to study the relationship between the specific energy and surface roughness
- to defining the energy saving strategies at the machining and process level.

Research aim and objectives

a. The aim of this work is to evaluate machining efficiency through surface finish of machined component.

b. To achieve this, cutting tests were carried out at different feed on titanium 6Al-4V alloy and

c. Specific energy and surface finish evaluated.

Research Methods

Cutting Experiment

Power Profile
Energy Consumption

Surface Roughness

Standardized NC toolpath

```
N1 G90 G21 G40 ...H00 G59
N2 T11 H11 E26
N3 G00 Y0.0 X00
N4 ..........................
...................
...............
.... M30
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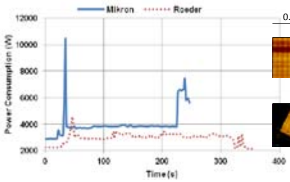
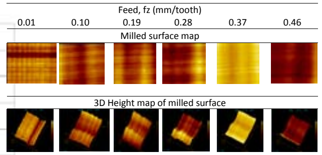
Milling process

Recording power

Power





Surface Map

Experimental details and Assessment

Workpiece materials: Titanium alloy 6AL-4V

Process: Side milling

Toolpath: Standardized to mimic an orthogonal side milling operation

Evaluation case

High Speed Machining (HSM)

	The University of Manchester, UK
HSM	Mikron HSM 400

Cutting parameters

	High speed machining
Machine tool	**Mikron HSM 400** 
Tool diameter (mm)	8
Workpiece material	titanium 6Al-4V alloy
No. of flutes	1
Depth of cut (mm)	3.5
Width of cut (mm)	0.25 – 1.00
Feed per tooth (mm/tooth)	0.01 – 0.55
Cutting Velocity(m/min)	80
Cooling	Dry

Undeformed Chip Thickness

The cutting test incorporate the optimum value of the radial width of cut model deduced from equations proposed by Balogun and Mativenga [17].

$$a_e = 0.23 \times r$$

$$h_{\max} = 0.64 f_z$$

Where, h_{max} is the maximum un-deformed chip thickness in *mm*, f_z is the chip load in mm/tooth and a_e is the step over or the radial depth of cut in mm.

Results: Machining efficiency and effects

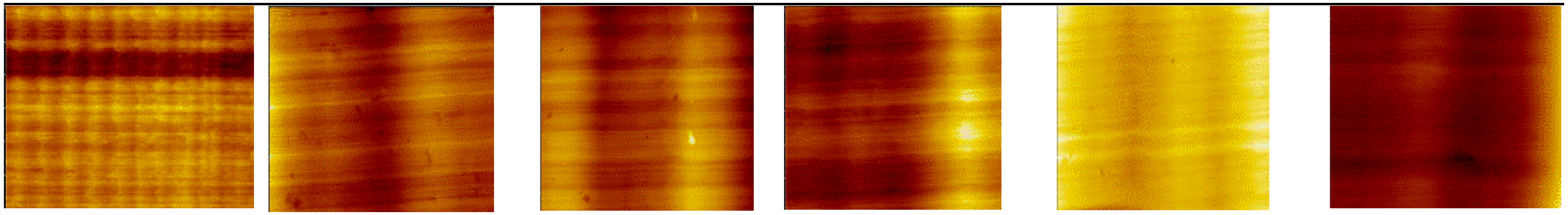
	Titanium alloy 6AL-4V					
V_c (m/min)	156	156	156	156	156	156
N (rpm)	6206	6206	6206	6206	6206	6206
f_z (mm/tooth)	0.010	0.100	0.190	0.280	0.370	0.460
Feed (mm/min)	62	621	1179	1738	2296	2855
a_p (mm)	3.50	3.50	3.50	3.50	3.50	3.50
a_e (mm)	0.92	0.92	0.92	0.92	0.92	0.92
MRR (mm^3/s)	3.33	33.31	63.28	93.26	123.24	153.21
Cutting Power (W)	0.12	0.18	0.22	0.23	0.1	0.1
Power (W)	86.26	129.38	158.14	165.32	71.88	71.88
Specific Energy Demand, k (J/mm^3)	10.66	4.45	3.28	2.55	2.65	1.14
Surface roughness (µm)	0.93	1.86	1.77	3.64	2.50	2.48

Surface and 3D height map after machining titanium alloy 6AL-4V

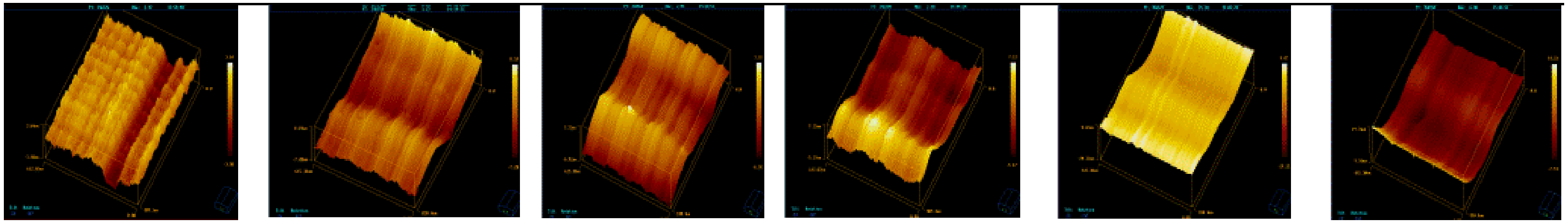
Feed, fz (mm/tooth)

0.01	0.10	0.19	0.28	0.37	0.46

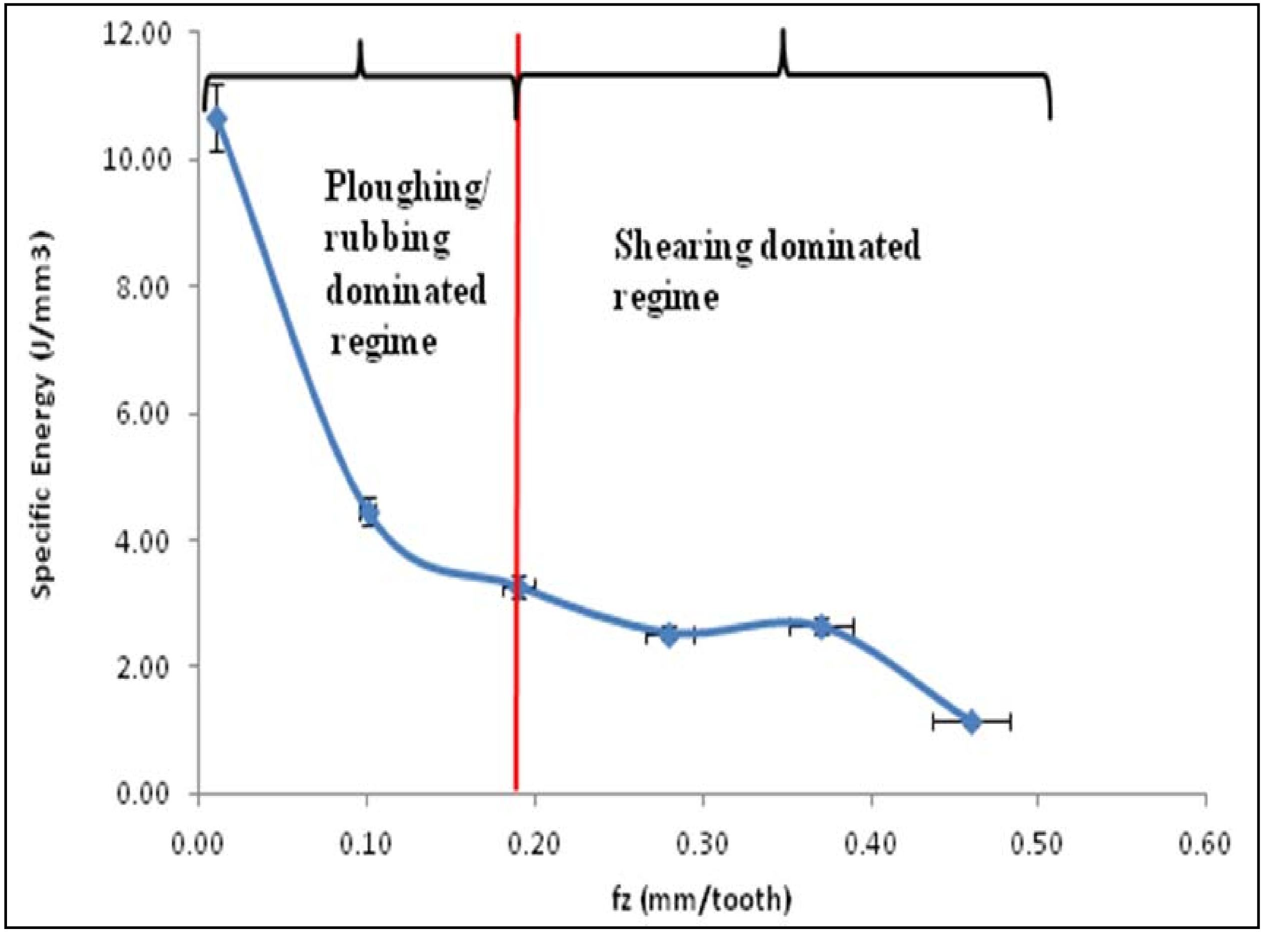
Milled surface map



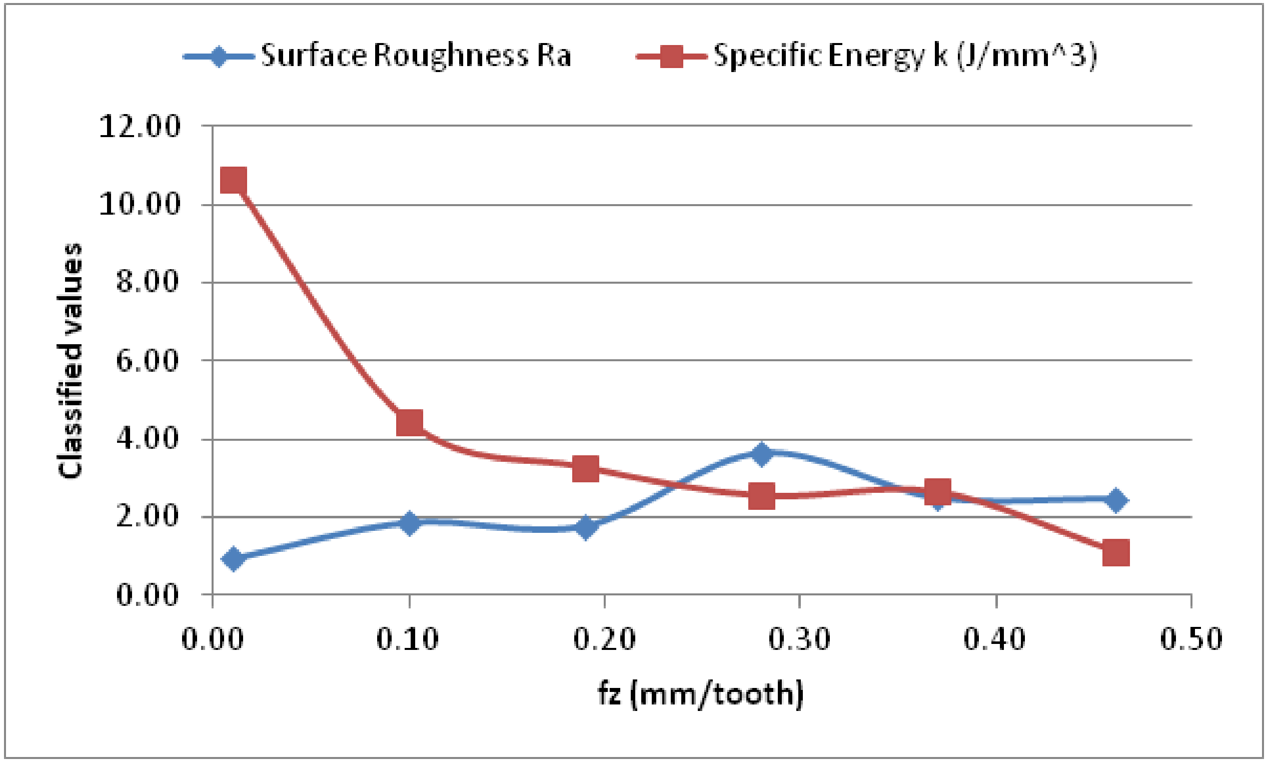
3D Height map of milled surface



Relationship between specific energy and chip load



Surface roughness and specific energy trade-off with feed after machining titanium alloy 6AL-4V



Conclusions

- Based on the observed and the analyzed data of the surface integrity and from the sustainability assessment of machining point of view, the following conclusions can be drawn:
- It is found that during machining of titanium alloy 6AL-4V, the specific energy decreases as the material removal rate increases.
- This is an evident of the transition of the process mechanisms from the ploughing dominated regime to the shearing dominated regime.
- This machining strategy reveals that shearing dominated machining should be promoted for sustainable machining.

Conclusions

- As the process mechanisms changes (i.e. feed increases), there tends to be a trade-off between the specific energy and surface roughness as they meet at a point well defined by the shearing process mechanisms.
- It is proposed that machining titanium alloy 6AL-4V should be conducted at range of feed fz between 0.19 µm and 0.37 µm.
- This is true because surface roughness is poor at lower specific energy.
- Therefore it is important to strike a trade-off point at which the aesthetic finish is defined by the acceptable surface roughness and at minimum specific energy demand and cost.

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Thank you