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Minimum Energy Criteria for Machining to Determine Energy-Productivity Relationship

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Abstract

In this research segment, cutting rates were changed while depth of cut and feed rate remained fixed. The results of cutting using a standard uncoated carbide insert were compared. Cutting speeds were maintained at a constant. After determining the optimal cutting condition for the equipment and material. To determine optimal tool life and cutting speed, turning operations were performed. In industrial cutting operations, flank wear reduces tool life. For single-point, rotating tools, 0.3 mm of flank wear is the cutoff for acceptable service life. Insert flank wear after 16 minutes of use at a velocity of 300 mm per min. It is possible to calculate the tool life exponent by first establishing a mathematical relation between the cutting speed and the logarithm of the tool life (log T). According to the pie chart's non-cutting area, the majority of the energy used during machining is not used for actual cutting. The machining process alone accounted for 35% of the total power used when operating Approximately 39%, 40%, and 41%, at a cutting speed of 300 mm/min. According to studies, consumes almost 98% of the total electricity used in the milling process. Only two percent of the power is consumed by the cutting process itself, depending on the load, machining used between 0% and 48.1% of the total energy. 63% reduction in energy consumption when comparing the actual cutting parameter used in a single run with the cutting parameter. This exemplifies how much energy could be conserved throughout the machining process if the minimal energy criterion were used.

Keywords: Uncoated and coated insert; Turning operations; Flank wear; machining; milling process; energy consumption; cutting parameter

INTRODUCTION

Titanium alloys are used more, especially in aerospace. Its characteristics make machining difficult. In particular, energy use and carbon emissions, which have a negative impact on the environment, are infrequently mentioned. Titanium's poor machinability slows and reduces machining. Given its large carbon footprint during ore extraction, employing this chemical must be minimized. This alloy is worth focusing on. This research standardized lathe and milling machine cutting testing. High speed machining's energy and carbon footprints were examined. The study reveals how process choice and cutting speed affect environmental footprints. According to the authors' earlier investigation, non-cutting lathe activity needed a disproportionate quantity of energy [1–4]. Demand-driven energy production adds to climate change and CO_2 emissions. Sustainable products require energy saving. Machining energy was reduced. Reducing energy use cuts CO_2 emissions. CES link carbon dioxide emissions to energy footprints. About 65% of the world's CO_2 emissions in 2000 were from the energy sector. The production of electricity and industrial activity accounted for 24% and 14% of CO_2 emissions,

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respectively. Energy consumption in industry must be reduced to reduce carbon emissions from energy production. According to research, most machining energy is consumed for non-cutting processes [5–7]. Two studies show that machining energy decreases as material is removed faster and compared the energy needed to machine a micro device to a standard [8]. Most of the available torque wasn't needed, therefore the Mazak machine drove the spindle with most of its energy. This example shows how choosing the correct machine can help a machined product save energy [9]. The money to buy new energy-efficient gear may not be available to industries. Also, low-energy micromachining centers can't create large components. Thus, it's vital to improve energy efficiency while using existing equipment. Reducing energy utilization helps sustain production. Sustainable manufacturing is the management of a product's whole life cycle, from design to distribution to disposal. Energy and material are conserved. World Commission on Environmental Development offered another view on sustainable development. Sustainable development is a transformation where resource exploitation, investment orientation, technology growth, and institutional change are congruent with present and future needs. Every industry should be sustainable to achieve global sustainability [10–14]. Consumption of technology goods rises with population, requiring more industrial output. A rise in demand for manufacturers indicates expansion. In contrast, increased demand will increase energy use. As the population grows, better education is needed [15–16].

Time and Energy Required for Machining Ti$_6$Al$_4$V Alloy

The end face of an 85 mm long by 42 mm wide block of titanium Ti6Al-4V alloy was machined using a milling machine. Tests were conducted under a wide variety of cutting conditions, which are detailed in Table 1.

Table 1. Milling operations' cutting conditions

Cutting parameters	**Range**
V_c [m/min] Cutting speed	30–80
N [RPM] Spindle speed	298–796
f_z [mm/tooth] Feed Rate	0.15
a_e [mm], Width of cut	4
Workpiece material	Ti6Al-4V
a_p [mm] Depth of cut	1
Insert type	Uncoated carbide
Numbers of inserts on tool holder	1
D [mm] Tool diameter	32

Table 2. Ti6Al4V alloy cutting parameters for milling

Speed [RPM]	298.42	397.89	497.36	547.1	596.83	696.3	746.04	795.77
Total power with idle spindle [W]	2745.8	2753.0	2760.2	2760.2	2767.3	2767.3	2774.5	2788.9
Current average during m/c [A]	3.88	3.89	3.9	3.91	3.91	3.92	3.95	3.95
Feed [mm/tooth]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Total power during m/c [W]	2788.9	2796.1	2803.3	2810.5	2810.5	2817.7	2839.2	2839.2
Table speed V_f [mm/min]	44.76	59.68	74.6	82.06	89.52	104.4	111.9	119.3
Current at idle spindle [A]	3.82	3.83	3.84	3.84	3.85	3.85	3.86	3.88
Power net for machining [W]	43.13	43.13	43.13	50.32	43.13	50.32	64.69	50.32
Cutting speed V_c [m/min]	30	40	50	55	60	70	75	80
MRR [mm^3/min]	179.05	238.73	298.4	328.2	358.1	417.7	447.6	477.4

This research segment varied cutting rates while maintaining feed rate and depth of cut (see Table 1 for details). Table 2 lists eight cutting conditions. An uncoated carbide insert was used for cutting comparisons [17–18]. After determining the optimal cutting condition for the equipment and material, we compared the resulting power and energy needs. The non-cutting or idle current consumption was measured immediately following machine startup. The voltage was measured and the current was logged under various cutting parameters [19–20].

A digital clamp metre model DT-266 was used to determine the current draw of the device. The voltage of the CNC milling machine's three-phase motor was tested with a clamp metre. Current consumption was also tracked during activities like rapidly returning the instrument to its starting position. Dry cutting was implemented to lessen the need for additional power sources [21–24].

Predicted Tooling Energy Consumption

Energy expended during the production of the cutting tool is not the same as the energy used during the actual machining operation. But it affects the system's total energy (machine inputs), which must be optimised. In order to create a tool, a substantial amount of energy must be expended, and this energy is mostly derived from the tool's basic components, procedure of sintering, process of grinding, and process of coating for certain instruments [25–26]. With this effort, we were able to produce estimates for the energy cost of tools. The energy contained in the tooling material was considered in Case 1, but in Case 2 only the energy expended during tool production was considered. Cases in point are provided in Table 3. Sintering was presumed to be the manufacturing method for the inserts used in this study, which was consistent with previous studies. Every insert was given its own coating. The average insert weight was calculated to be 9.5 g.

IMPROVEMENT OF TURNING TOOLS FOR EXTENDED UTILIZATION (TOOL LIFE)

To investigate the cutting conditions, perform in determining the ideal tool life and, by extension, the optimal cutting velocity, a series of turning operations were carried out [27–28]. The experiments used a 900 mm long, cylinder-shaped billet of EN8 steel (AISI 1040), and outcomes are concise in Table 3: Energy to make an insert tool. It has been partitioned into three separate sections for the milling process. Table 4 displays the material make-up of the workpiece. With the help of a Vickers hardness tester, calculated that the mean hardness was 160 HV, the plates measured 300 mm in length and 130 mm in width. Using CNC lathe, parts were manufactured. For the previously mentioned reasons, the tests were carried out using dry machining and a tool holder, and the trials employed grade 1015 inserts in the cutting tools.

Table 3. Insert tool development energy

	Case 1	**Case 2**
Coatings and Sintering (MJ per process/cutting insert)	1–3	1 to 3
Energy of embodied tool material (MJ/kg)	430	-
Total energy /insert (MJ)	3.1	1.7

Table 4. Material composition of EN8 workpiece

Phosphorous	**Manganese Mn**	**Silicon Si**	**Sulfur S**	**Iron Fe**	**Carbon C**	**Silicon Si**	**Molybdenum Mo**
0.05%	0.8%	0.1%	0.05%	98.5%	0.4%	0.1%	0.1%

FLANK WEAR

Flank wear affects tool life in industrial cutting applications. For single-point, rotating tools, 0.3 mm of flank wear is the cutoff for acceptable service life. Insert flank wear after 16 minutes of use at a velocity of 300 mm per minute is depicted in Figure 1. The flank wear at three different cutting speeds is quantified in Figure 2. Cutting velocity and flank wear are linked by data. Cutting speed, not cut depth or feed rate, determines traditional machining tool wear, according to. The cutting speed was increased to 300, 400, and 500 mm/min, and the wear was measured while the feed rate and depth of cut remained constant at 0.15 mm/rev and 1 mm, respectively. The cutting tool maker recommended retaining cutting conditions. A digital clamp meter onto the MHP lathe's power cord to measure its current. Current readings were acquired after turning on the apparatus to calculate power usage. Before starting the spindle, all tools were in place. The spindle's current was then measured when it wasn't cutting. Current was measured while the cutting tool was moved to determine axis jog. Total machining current was recorded. Inserts were inspected at regular intervals during cutting and afterward.

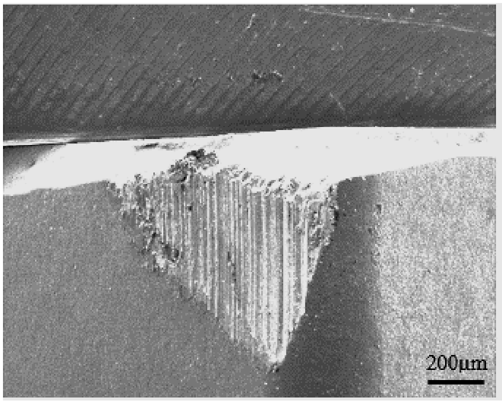

Figure 1. microscopic view of flank wear.

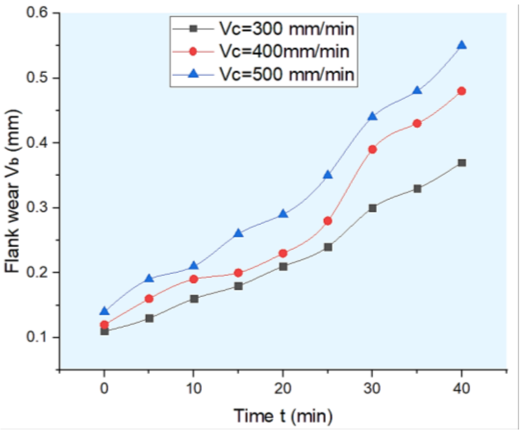

Figure 2. Variable flank wear according to the cutting speed.

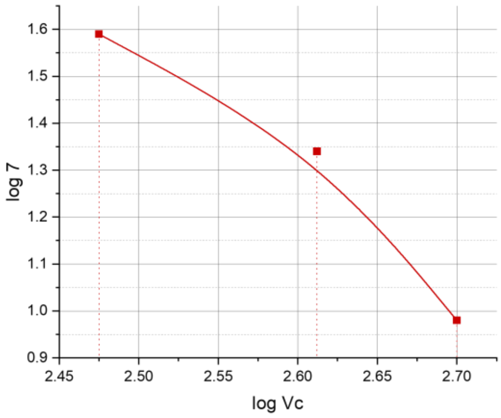

Figure 3. Availability of tools for various cutting rates.

Tool-life

The cutting velocity exponent for the tool life can be derived from the linear relationship between the log scale of tool-life (log T) and cutting speed shown in Figure 3. The log tool-life scale multiplied by the cutting speed will yield this exponent. For milling EN8 steel, this equates to an exponent of cutting speed of 2.4 for these inserts. With this number, we can calculate the optimal tool lifetime for lowest energy consumption.

USING CUTTING SPEED TO DETERMINE ENERGY DISTRIBUTION

Figure.4 shows blade speed power distributions. The machine must be turned on with the spindle disabled to calculate power usage. The idle power equals the machine's module and spindle power usage. The term "machining power" refers to the sum of all energy expended throughout the machining process, excluding the energy needed to run the machine itself. The quantity of machining power used is dependent on the pace of material removal and the type of workpiece being machined [29–33]. The majority of the energy consumed during machining is not used in the actual cutting process, as shown by the non-cutting section of the pie chart. The machining process alone accounted for 35% of the total power used when operating at a cutting speed of 300 m/min, 39%, 40%, and 41%, respectively, depending on the load of the machine, found that the distribution of power during milling varied from 0% to 48.1%. According to the results of this research, a significant amount of energy and electricity is used during the cutting process by the machine modules themselves. To minimize the effect that manufacturing has on the environment, it is important to select and design machines that have a small energy footprint and a high power efficiency.

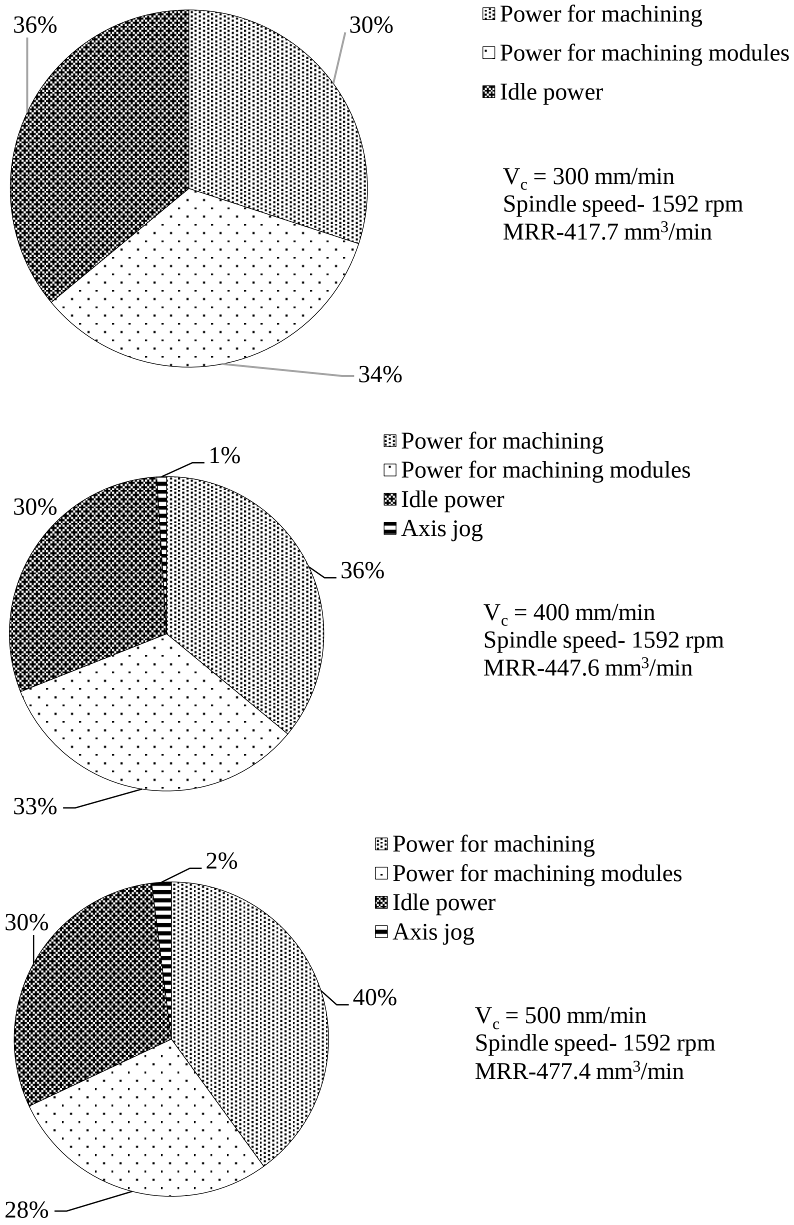

Figure 4. Distribution of Power for Variable Cutting Rates.

RESULTS AND DISCUSSIONS

Various cutting speeds were used to calculate power. Figure 5 shows power savings versus entire usage. Figure 6 shows that the non-cutting power is equal to the difference between the total power and the cutting power, electricity is required to run the equipment with zero loads. The non-cutting procedure used 98% of the energy. So, milling utilized less than 2% of the total electricity. Reduced spindle energy needs while turning a lightweight cutting tool vs. a heavy workpiece are a factor. As cutting speed increased, so did machining power, the research showed. Calculating specific power at varied elimination rates gave us the substance's specific energy. Figure 6 shows power consumption as a function of Ti6Al4V milling MRR on a milling machine. Measured power is cutting force (net power for machining). The energy needed to turn on the spindle when no cutting was happening was proportional to spindle speed. Figure 6 's cutting power of 3.7 Wsmm^{-3} for titanium alloy say 2–5 Wsmm$^{-3.}$ R2 = 0.55 in Figure 6 shows a significant link between data distributions and the straight line.

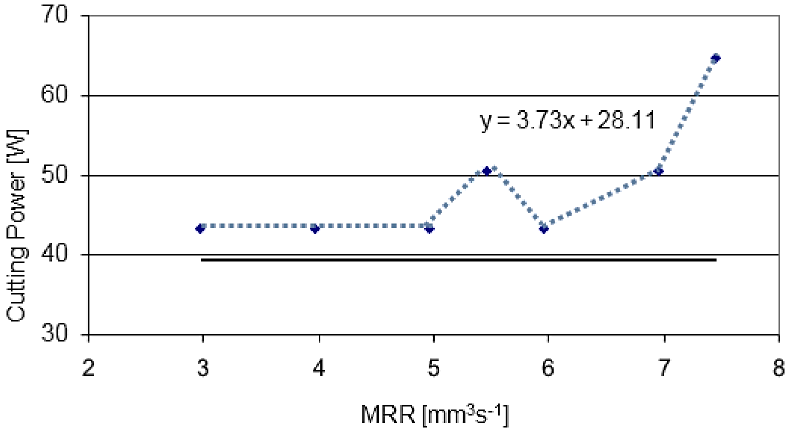

Figure 5. Power usage varies with the rate of material removal.

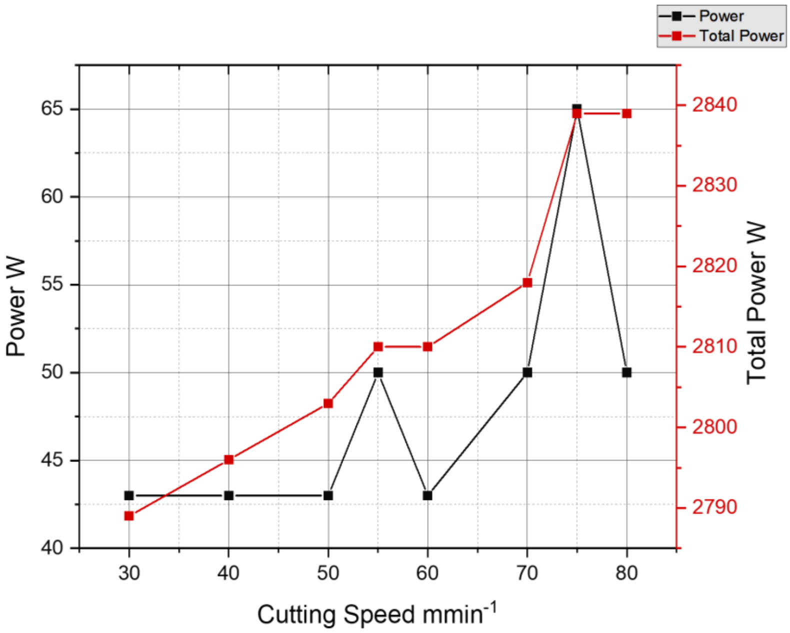

Figure 6. Power requirements of a computer numerically controlled milling machine in different settings.

Further experimentation was done on cutting conditions at 75 mm/min, 1 mm depth of cut, 0.15 mm/tooth feed. The power distribution in this cutting scenario is shown in Figure 7.

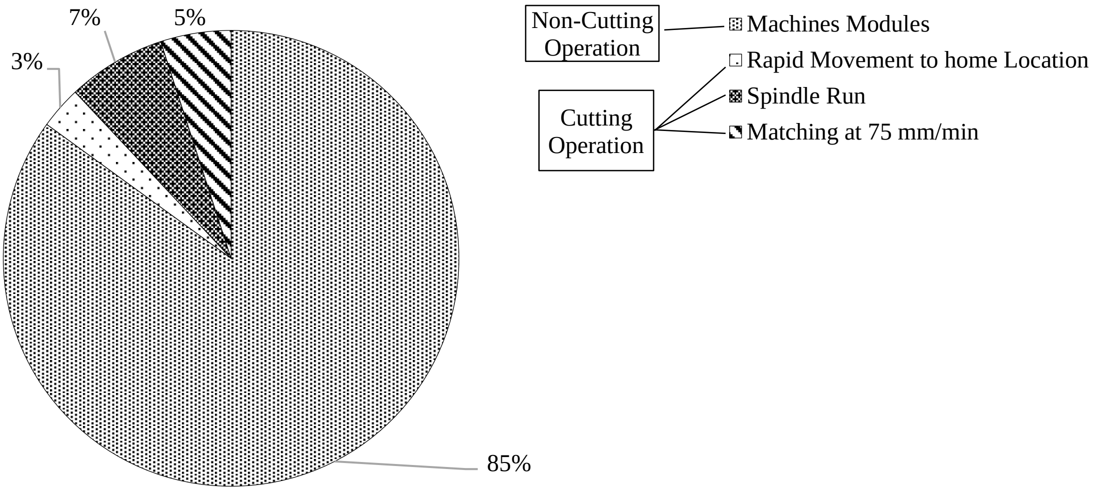

Figure 7. Distribution of power on a 746 RPM, CNC-controlled milling machine.

In terms of power, there are two factions. Energy used for non-cutting jobs is the first category. Non-cutter operations include energy needed to switch on machine parts. P = 2.7 kilowatts was the current needed to power on the machine modules. After then, a 0.03 A current (P = 21.56 W) was used to fast reset the axes (jog). The final step used 0.03 A current (P = 21.56 W) and a spinning, non-cutting spindle. This represents 98% of milling electricity, according to our analysis. Cutting uses 2% of energy. Depending on demand, machining used 0%–48.1% energy. The milling machine uses most of its energy when idle, which is intriguing. This means that turning on a machine affects the quantity of energy needed to execute the task. Idling equipment increases its carbon impact. In the study, milling and lathe energy profiles were evaluated under similar material removal conditions (feed rate of 0.15 mm/rev, cutting speed of 75 m/min, and depth of cut of 1 mm). Figure 8 demonstrates that milling operations consume less energy than lathe operations. Because the workpiece is held in place by the spindle during lathe operations, turning a larger piece will require more energy. Most milling spindles only contain a single, small cutting tool, which significantly lowers the load on the motor. The energy needed to position the tool is incredibly low compared to other processes.

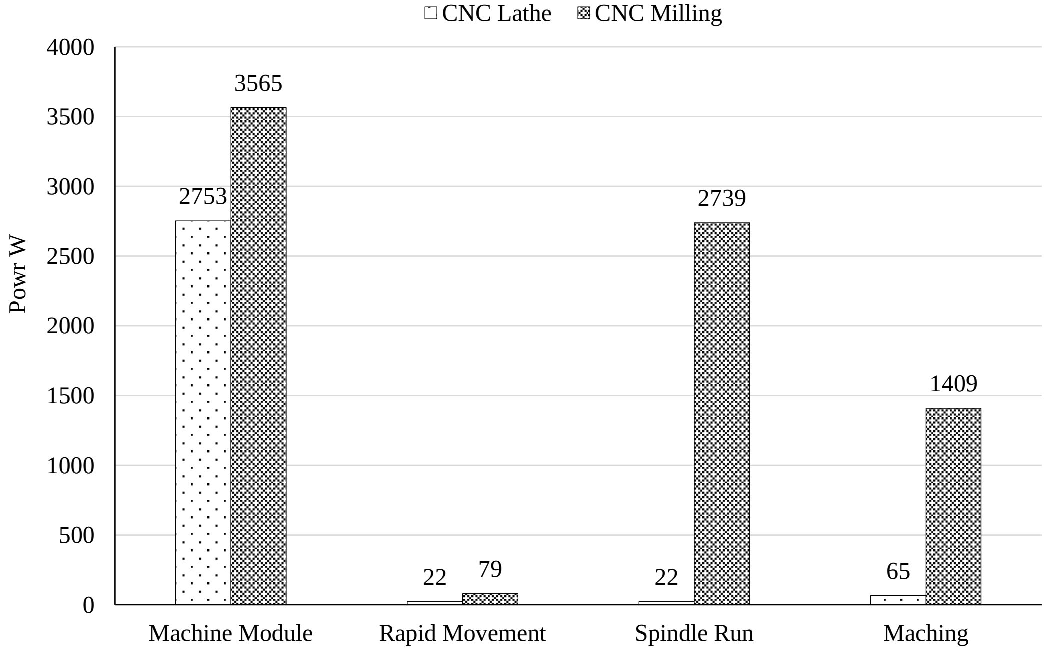

Figure 8. Results of cutting conditions on a CNC milling vs lathe.

Results from both machining centers show that machine modules or standby power play a crucial role in the process. With almost 18% of the power going toward the cutting motion in lathe machining, it is apparent that this method is more efficient than the other.

Table 5 displays estimates of the energies required by each machine to process 10 cm^3 of Ti_6Al_4V for removal. The results reveal that more energy is required for milling to remove 10 cm^3 of Ti_6Al_4V than for lathe machining. This outcome occurs because milling has a slower rate of material removal. Since milling takes longer than turning (in this case, to remove 10 cm^3), more power is needed to accomplish the same task. In order to remove 10 cm^3 of Ti_6Al_4V, the lathe requires more power, but the power is distributed more evenly and uses less energy overall. Machining's "spindle factor" influences power distribution and energy usage. The rate at which materials are being removed is another crucial aspect to think about. A faster rate of material removal results in less time needed to process a given amount of material. In the end, this meant less power was used throughout the milling operation.

Table 5. Specifications for cutting on a milling and lathe machine

Parameters	**lathe**	**Milling**
Cutting speed [m/min]	75	75
Feed	0.15 mm/rev	0.15 mm/tooth
Depth of cut [mm]	1	1
Time taken to remove 10 cm^3 [min]	0.9	22.3
Energy for actual cutting [MJ]	0.08	0.09
Material removal rate [mm^3/min]	11056	447
Total energy for machining [MJ]	0.42	3.81

Increasing cutting speeds affected power consumption. After factoring in time and power, the energy needed to clear 10 cm^3 of material from the workpiece was calculated. CO_2 emissions were calculated using the power source's 0.43 kg CO_2 e/kWh carbon fuel emission factor. To emphasize the changes caused by milling, the CO_2 emission was estimated without adding the CO_2 released in manufacturing 10 cm^3 of titanium alloy raw material. Figure 9 shows how cutting speed affects carbon emissions and machining energy.

Figure 10 shows Carbon emissions and machining energy for milling 10 mm^3 of Ti_6Al_4V alloy decreases with increasing cutting speed. When the overall amount of energy used in manufacturing is decreased, carbon emissions drop in direct proportion. This data demonstrates the need of analysing cutting conditions while looking for items with a minimal effect on the environment's energy supply. The highest cutting speed (Vc = 80 mm/min) results in a 75% reduction in CO_2 emissions from the baseline value of 1.12 kg CO_2 at 30 mm/min^{-1}. The environmental impact has been greatly reduced, by roughly 62%.

Optimal Cutting Speed is Selected Utilizing Minimal Energy Criterion

Cutting velocity exponents, operating machine module power (P0), tool change time (t3), and energy per tool cutting edge are needed to determine the greatest tool life with the least amount of energy. The MHP Lathe produced 3.594 kW, needed two minutes to change the insert, and had a cutting velocity exponent of 2.4. Figure 9 (a) depicts the ideal tool life and energy usage for the two situations under consideration. After calculating the power needed to make the tool and the material's energy use, the optimal tool life was 11.4 minutes. Changes to the system's boundaries and ignoring the cutting tool's energy result in a 5.2-minute optimum tool-life. According to least cost, tool life should be 10 minutes. Figure 9 (b) displays the results of applying the tool-life equation to these ideal values to determine the ideal cutting speed. As indicated, the least cost condition was met at 511 m/min. The best cutting speed was 484 mm/min when tool energy was included and 671 mm/min when it wasn't. When only insert energy (Case 2) is considered, the best cutting speed is higher than the tool provider's range (335 mm/min to 555 mm/min). This means the cutting tool's energy footprint affects how efficiently the least energy criterion and maximum production rates may be reached.

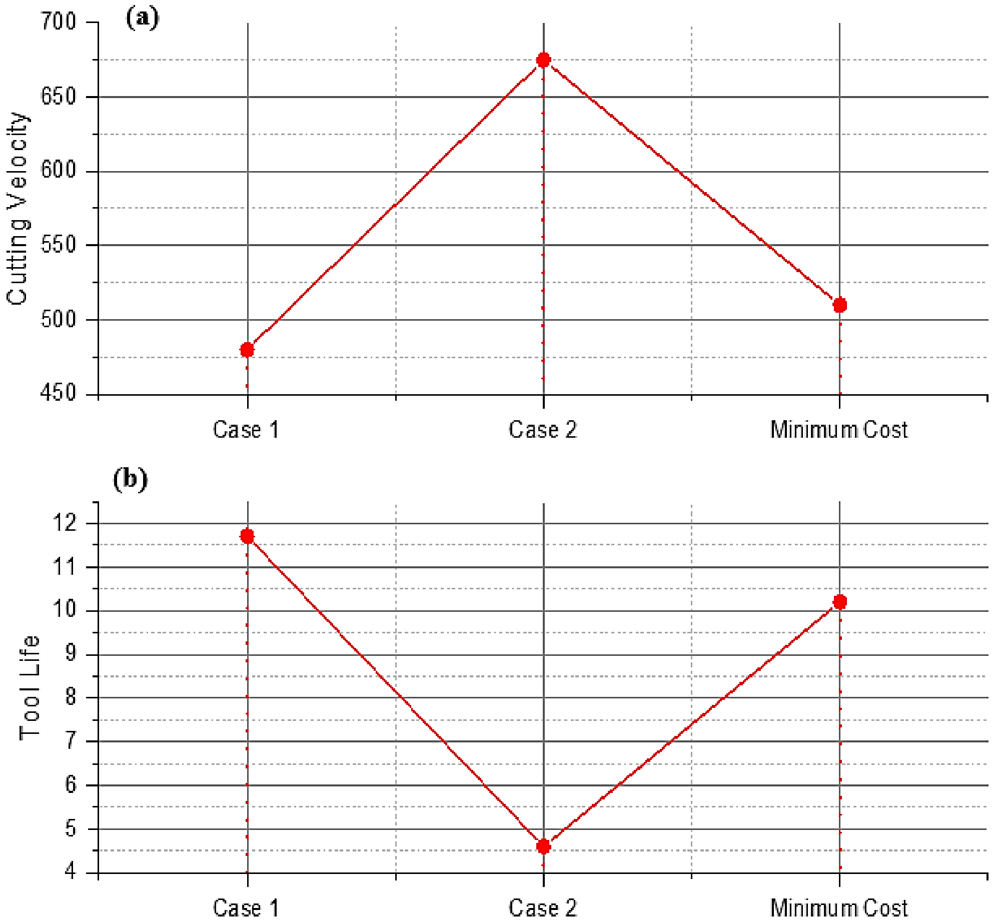

Figure 9. (a) Cutting velocity with different factors (b) Tool-life improvement using different factors.

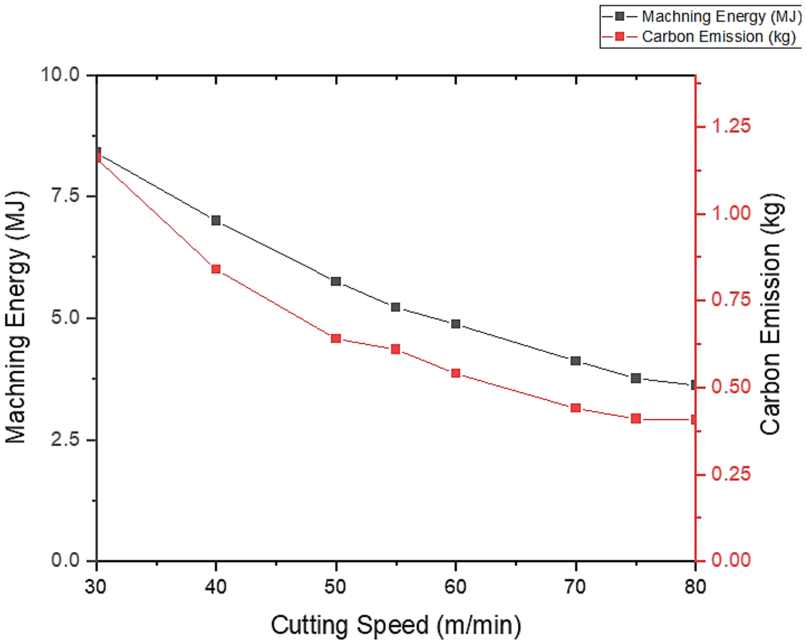

Figure 10. Carbon dioxide emissions and energy used to mill 10 mm^3 of titanium alloy.

Table 6. Minimum energy cutting speed [mm/min], *Vc* = 3.02

		Cutting speed								
ap [mm] Depth of cut	4.00	546	468	420	385	360	339	322	308	296
	3.75	549	471	422	388	362	341	324	310	298
	3.50	553	474	424	390	364	343	326	312	299
	3.25	556	477	427	392	366	345	328	314	301
	3.00	560	480	430	395	369	348	330	316	303
	2.75	564	483	433	398	371	350	333	318	306
	2.50	569	487	437	401	374	353	336	321	308
	2.25	574	492	441	405	378	356	339	324	311
	2.00	580	497	445	409	382	360	342	327	314
	1.75	587	503	451	414	386	364	346	331	318
	1.50	594	509	457	419	391	369	351	335	322
	1.25	604	517	464	426	397	375	356	341	327
	1.00	616	527	473	434	405	382	363	347	333
	0.75	631	541	485	445	415	392	372	356	342
	0.50	653	560	502	461	430	406	385	368	354
	0.25	694	594	533	489	456	430	409	391	376
Feed rate		0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
		feed [mm/rev]								

Maximum cutting speed at lowest energy [m/min], Vc 3.02 (Table 6). The CNC employed in this study's spindle motor power maximum is shown in Figure 11. Other machine parts, such as the computer, motor, coolant, and hydraulic pump, required power in addition to the turret. The amperage should be kept below 60 A, according to the manufacturer (power equal to 40.3 kW). Knowing the limits of the machine and spindle is essential during milling.

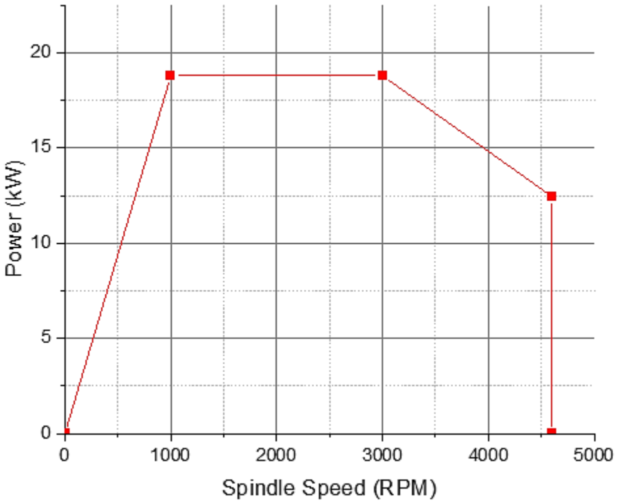

Figure 11. The lathe's spindle motor's maximum power.

To investigate the machine tool's electrical energy requirements, cutting experiments were conducted. The machine's current operating profile is shown in Figure 11. When the machine spindle is turned on or off, the amount of electricity used increases quickly. The highest current that is allowed for safety is 75 A, and the peak current did not go over that level. They all function at a current that is lower than 55 A., which is well within the recommended operating range. The total amount of energy consumed was calculated based on the average current during all of the passes. By multiplying this by the amount of time needed for each pass, the energy expended may be determined.

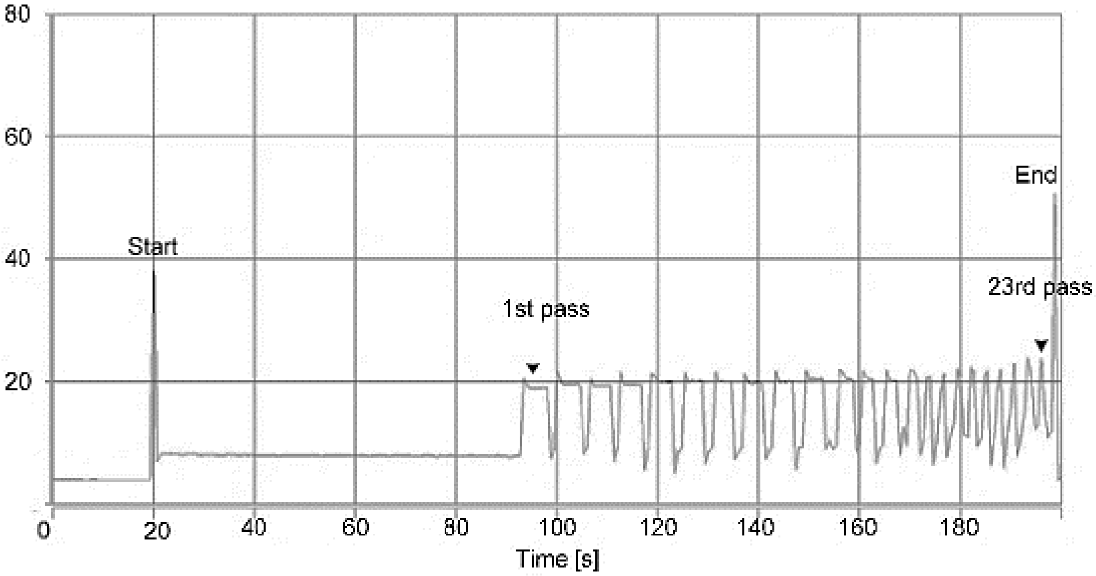

Figure 12. Measured necessary power input.

By locating the region under the graph, one may estimate the total quantity of energy consumed. Before any actual cutting was done, The graph's first segment shows the results of turning on the machine and the spindle. Energy consumption was also determined by turning the spindle at various speeds without a workpiece or load. Figure 12 depicts the calculated input power requirements.

Table 7. Comparison between the best cutting parameter and the parameter that the tool seller recommends

	Tool supplier parameter	**Mid-process parameter**	**Minimum-cost parameter**	**Minimum energy parameter**
D_C (Depth of cut) [mm]	1	2	4	4
F_R (Feed rate) [mm/rev]	0.3	0.3	0.15	0.15
C_V (Cutting speed) [m/min]	415	382	341	341
Volume removed [mm^3]	15240	30172	59112	59112
Total energy [kWs]	535.8	603	760	760
MRR [mm^3/s]	2075	3816	3408	3408
Energy per volume removed [Ws/mm^3]	12.50	20	12.85	12.85
Tool-supplier-based parameter difference	-	43%	63%	65%

Table 7 shows a 65% reduction in energy consumption when comparing the actual cutting parameter used in a single run with the cutting parameter. This exemplifies how much energy could be conserved throughout the machining process if the minimal energy criterion were used. In addition to lowering manufacturing costs, this improvement will aid businesses in creating a more environmentally friendly machining process.

Parameters for Cutting a Step Shaft that Meet an Energy Minimization Requirement

Machining requires multiple passes in practise. Figure 13 demonstrates how a cylindrical billet can be machined into a step shaft in four passes from 100 mm to 92 mm (the cutting parameters advised by the tool manufacturer were used). Cutting parameters are listed in Table 7.

Tables 8 and 9 compared a number of useful cutting parameters. The manufacturer's cutting settings increased energy use and production costs, according to the data. This energy-wasting method is essential.

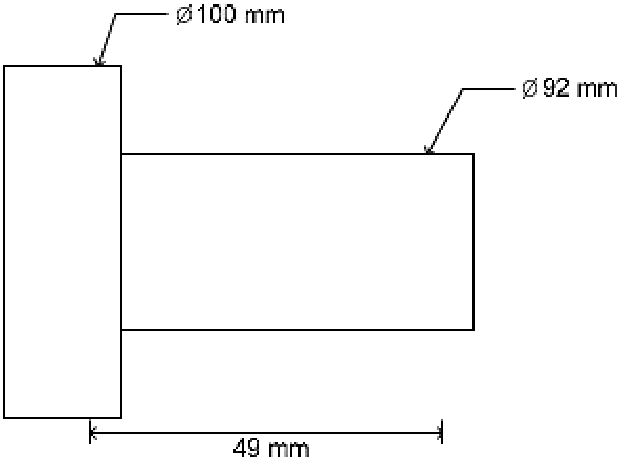

Figure 13. Step shaft.

Table 8. Value depending on the optimum cutting parameter

Pass	**First**	**Second**	**Third**	**Fourth**	**Total**
t_2 [min]	0.12	0.12	0.12	0.11	0.47
N [RPM]	1334.33	1361.84	1390.51	1420.42	-
MRR [mm^3/s]	2075.00	2075.00	2075.00	2075.00	-
Total Energy [kWs]	540.21	526.52	538.47	529.60	2134.80

Table 9. In-depth comparision of the relationship between two sets of cutting parameters

	Tool supplier parameter	**Mid-process parameter**	**Minimum-cost parameter**	**Minimum energy parameter**
Total energy [kWs]	2138.5	1206	760	760
Tool supplier-based parameter difference	-	44%	64%	65%
Energy per volume removed [Ws/mm^3]	36.18	20.40	12.85	12.85
No of passes	4	2	1	1
Total volume removed [mm^3]	599112	599112	599112	599112

CONCLUSIONS

In this portion of the experiment, several cutting speeds were employed while maintaining a consistent feed rate and depth of cut. Analyses were done on the cutting efficiency of a general-purpose uncoated carbide insert. The cutting speeds achieved their goals. The cutting procedure began when the instruments and material's optimal cutting conditions were determined. The turning operations were performed to find out how the cutting situations affect tool life and cutting speed. This was done so that cutting speeds could be maximised. In industrial cutting, flank wear can shorten the tool's lifespan. For a reasonable service life, spinning tools with a single point need 0.3 millimetres of flank wear. After 16 minutes of use at 300 mm/min, replace the flank wear insert. The pie chart's "non-cutting" section shows that most of the machining process's energy is not used for cutting. The chart reveals this. When running at 300 m/min, the machining process alone used 35% of the total power. Milling consumes 98% of power, according to the study. Only 2% of energy is used for cutting. Energy consumption dropped 63% when comparing the cutting parameter to the one utilised in a single run. Machining energy ranged from 0% to 48.1% depending on load. If the minimal energy criterion were applied, this shows how much energy could be preserved throughout the machining process.

By eliminating unnecessary variables, the direct search approach pinpoints the parameters conducive to a long tool life and low energy footprint. The machine's spindle power alone won't be enough to achieve maximum energy efficiency, but also the spindle power utilised by the overall machining resource and its reliance on spindle speed. The spindle speed affects the machine and spindle module's energy utilization in machining (in RPM). The case study found that choosing cutting conditions with the lowest energy footprint can reduce a machined product's energy footprint by up to 65%.

REFERENCES

1. Camposeco-Negrete C. Optimization of cutting parameters using Response Surface Method for minimizing energy consumption and maximizing cutting quality in turning of AISI 6061 T6 aluminum. Journal of cleaner production. 2015 Mar 15;91:109–17.
2. Rajemi MF, Mativenga PT. Machinability analysis from energy footprint considerations. Journal of Machine Engineering. 2008;8.
3. Uhlmann E, Koenig J. Key technologies for sustainable manufacturing. Journal of Machine Engineering. 2008;8.
4. Kumar R, Bilga PS, Singh S. Optimization of Turning Parameters Using Taguchi Method for Reducing Active Cutting Energy. InProceedings of the 7th International Conference on Advancements in Engineering & Technology (ICAET-2019), Sangrur, India 2019 Mar (pp. 15–16).
5. Zhong Q, Tang R, Peng T. Decision rules for energy consumption minimization during material removal process in turning. Journal of Cleaner Production. 2017 Jan 1;140:1819–27.
6. Dambhare S, Deshmukh S, Borade A, Digalwar A, Phate M. Sustainability issues in turning process: A study in Indian machining Industry. Procedia CIRP. 2015 Jan 1;26:379–84.
7. Uhlmann E, Koenig J. Key technologies for sustainable manufacturing. Journal of Machine Engineering. 2008;8.
8. Singh BK, Roy H, Mondal B, Roy SS, Mandal N. Measurement of chip morphology and multi criteria optimization of turning parameters for machining of AISI 4340 steel using Y-ZTA cutting insert. Measurement. 2019 Aug 1;142:181–94.
9. Park HS, Nguyen TT, Dang XP. Multi-objective optimization of turning process of hardened material for energy efficiency. International Journal of Precision Engineering and Manufacturing. 2016 Dec;17(12):1623–31.
10. Awale A, Inamdar K. Multi-objective optimization of high-speed turning parameters for hardened AISI S7 tool steel using grey relational analysis. Journal of the Brazilian Society of Mechanical Sciences and Engineering. 2020 Jul;42(7):1–7.
11. Gutowski T, Dahmus J, Thiriez A. Electrical energy requirements for manufacturing processes. In 13th CIRP international conference on life cycle engineering 2006 May 31 (Vol. 31, No. 1, pp. 623–638). Leuven, Belgium.
12. Ogundimu O, Lawal SA, Okokpujie IP. Experimental study and analysis of variance of material removal rate in high speed turning of AISI 304L alloy steel. InIOP conference series: materials science and engineering 2018 Sep 1 (Vol. 413, No. 1, p. 012030). IOP Publishing.
13. Chaturvedi R, Sharma A, Sharma K, Saraswat M. Tribological behaviour of multi-walled carbon nanotubes reinforced AA 7075 nano-composites. Advances in Materials and Processing Technologies. 2022 May 29:1–3.
14. Rajemi MF, Mativenga PT, Aramcharoen A. Sustainable machining: selection of optimum turning conditions based on minimum energy considerations. Journal of Cleaner Production. 2010 Jul 1;18(10–11):1059–65.
15. Jain H, Tripathi J, Bharilya R, Jain S, Kumar A. Optimisation and evaluation of machining parameters for turning operation of Inconel-625. Materials Today: Proceedings. 2015 Jan 1;2(4–5):2306–13.
16. Mori M, Fujishima M, Inamasu Y, Oda Y. A study on energy efficiency improvement for machine tools. CIRP annals. 2011 Jan 1;60(1):145–8.
17. Newman ST, Nassehi A, Imani-Asrai R, Dhokia V. Energy efficient process planning for CNC machining. CIRP Journal of Manufacturing Science and Technology. 2012 Jan 1;5(2):127–36.

18. Sharma A, Chaturvedi R, Sharma K, Saraswat M. Force evaluation and machining parameter optimization in milling of aluminium burr composite based on response surface method. Advances in Materials and Processing Technologies. 2022 Feb 20:1–22.
19. Velchev S, Kolev I, Ivanov K, Gechevski S. Empirical models for specific energy consumption and optimization of cutting parameters for minimizing energy consumption during turning. Journal of cleaner production. 2014 Oct 1;80:139–49.
20. Camposeco-Negrete C. Optimization of cutting parameters using Response Surface Method for minimizing energy consumption and maximizing cutting quality in turning of AISI 6061 T6 aluminum. Journal of cleaner production. 2015 Mar 15;91:109–17.
21. Wang Q, Liu F, Wang X. Multi-objective optimization of machining parameters considering energy consumption. The International Journal of Advanced Manufacturing Technology. 2014 Mar;71(5):1133–42.
22. Sun J, Yan G, Abed AM, Sharma A, Gangadevi R, Eldin SM, Taghavi M. Evaluation and optimization of a new energy cycle based on geothermal wells, liquefied natural gas and solar thermal energy. Process Safety and Environmental Protection. 2022 Dec 1;168:544–57.
23. Singh PK, Sharma K. Mechanical and viscoelastic properties of in-situ amine functionalized multiple layer grpahene/epoxy nanocomposites. Current Nanoscience. 2018 Jun 1;14(3):252–62.
24. Buratti E. Simulations of Ti6Al4V milling for assessing different cooling lubrication strategies.
25. Ogundimu O, Lawal SA, Okokpujie IP. Experimental study and analysis of variance of material removal rate in high speed turning of AISI 304L alloy steel. InIOP conference series: materials science and engineering 2018 Sep 1 (Vol. 413, No. 1, p. 012030). IOP Publishing.
26. Makadia AJ, Nanavati JI. Optimisation of machining parameters for turning operations based on response surface methodology. Measurement. 2013 May 1;46(4):1521–9.
27. Xiao Y, Jiang Z, Gu Q, Yan W, Wang R. A novel approach to CNC machining center processing parameters optimization considering energy-saving and low-cost. Journal of Manufacturing Systems. 2021 Apr 1;59:535–48.
28. Mativenga PT, Rajemi MF. Calculation of optimum cutting parameters based on minimum energy footprint. CIRP annals. 2011 Jan 1;60(1):149–52.
29. Mori M, Fujishima M, Inamasu Y, Oda Y. A study on energy efficiency improvement for machine tools. CIRP annals. 2011 Jan 1;60(1):145–8.
30. Newman ST, Nassehi A, Imani-Asrai R, Dhokia V. Energy efficient process planning for CNC machining. CIRP Journal of Manufacturing Science and Technology. 2012 Jan 1;5(2):127–36.
31. Mawson VJ, Hughes BR. The development of modelling tools to improve energy efficiency in manufacturing processes and systems. Journal of Manufacturing Systems. 2019 Apr 1;51:95–105.
32. Wang S, Lin H, Abed AM, Sharma A, Fooladi H. Exergoeconomic assessment of a biomass-based hydrogen, electricity and freshwater production cycle combined with an electrolyzer, steam turbine and a thermal desalination process. International Journal of Hydrogen Energy. 2022 Sep 15;47(79):33699–718.
33. Velchev S, Kolev I, Ivanov K, Gechevski S. Empirical models for specific energy consumption and optimization of cutting parameters for minimizing energy consumption during turning. Journal of cleaner production. 2014 Oct 1;80:139–49.