Smart Selection of Cutting Tool for Work Part Under Sustainability Considerations

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Abstract: ***A mathematical study for smart selection of cutting tool for a particular work part has been presented. The sustainability considerations such as greenhouse gas and other considerations of economy, tool life, and design have been included. For machining operations, we have large number of cutting tool materials from carbon steel to ceramics and diamond are included. Out of all these cutting tool materials, it is difficult to select a cutting tool which meets all the sustainability requirements including GHG emission, surface finish, cost, and recyclability The suitability and selection of a cutting tool material for a work part material under sustainability consideration has been the main driving force. A computer software on MATLAB has been developed which can select the most suitable cutting tool material for a work material. In particular we analyze the following properties of cutting tool material; high hot hardness, CO2 NOx, SO_2, and mercury (GHG) emissions. These emissions depend largely on the cutting tool geometry and minimize the heat generation during machining. The effect of tool geometry for energy minimization is studied for sustainable manufacturing. The greenhouse gas (GHG) emission has been analyzed in terms of rake angle (α) . The shear force (Fs) decreases as rake angle increases. Subsequently the reduction in horse power requirement will affect the GHG emissions. How much CO2 is emitted in air during machining has been quantified. The friction force (F) declines very rapidly as rake angle (α) increases and reduce the lubricant requirement during machining. The study of total specific energy (TSE) the summation of specific process energy (SPE) and specific constant energy (SCE) in machining also included.***

1. Introduction

In today's metalworking industry, many types of materials, ranging from high carbon steel to ceramics and diamonds, are used as cutting tools. Because of the wide range of conditions and requirements, no single cutting tool material meets all the needs of machining operations. Each tool material has its own properties and characteristics that make it best for a specific metalworking application. While evaluating a cutting tool material for a machining operation, the applicability is dependent on having the correct combination of its physical properties. Thus, it is extensively important to select the most appropriate cutting tool material with the desired properties for enhanced machining performance. This paper presents smart selection of work material and cutting tool combination mathematically.An outstanding feature is the turret in place of the tailstock. This turret mounted on either the sliding ram or the saddle, or on the back of the structure, carries anywhere from 4 to 18 tool stations. The tools are preset for the various operations. These tools are mounted in proper sequence on the various faces of the turret so that as the turret indexes between machining operations, the proper tools are engaged into position. For each tool there is a stop screw or electric/electronic transducer, which controls the distance the tool will feed and cut. When this distance is reached, an automatic trip lever stops further movement of the tool by disengaging the Many types of cutting tools materials, ranging from high carbon steel to ceramics and diamonds, are available in market. Because of the wide range of conditions and requirements, no single cutting tool material meets all the needs of machining applications. In this research we are considering a list of 5 cutting tool materials from environmental impact viewpoints. Here cutting tool materials performance are evaluated based on power consumption, GHG emissions, and temperature including the surface finish are considered. Each cutting tool material has its own properties and characteristics that make it best for a specific application of work material. The right combination of its physical properties work material and cutting tool material will give least GHG emissions and surface roughness There are many forces that occur during the cutting operation, like friction force between the chip face and the tool face, and shear force that occurs on the shear plane. However, during the manufacturing operation if the shear force and the cutting force show favorable conditions such that the operation will be successful, then it is concluded that all the other forces will also have favorable conditions, as these two forces are the strongest forces responsible for the removal of materials The statements mentioned about the metal working operation are true, regardless of the material/tool combination. Rake angles is the angle of cutting force relative to the work. Generally, the positive rake angle makes tool sharper, and most important it reduces the requirement of cutting force and power requirement. Therefore, the processes become environmentally conscious and sustainable including less GHG emissions. A zero-rake angle is easiest to manufacture, but has the larger crater when compared to positive rake angle. However, recommended rake angle can vary with work material and the tool material. That's one of the reasons for the analysis presented in this article. In literature there are wide variation in recommendation for material and rake angle combination. It is being presented in the Table 1.

Table 1: Recommended Rake Angle for Work material

Material cut	Rake (α) (2)	Rake (σ) (3)	Rake (α) (4)
Aluminum	12^0-25^0	40^0	35^0
Bronze	5^0-14^0		0^0
Brass	3^0-14^0	8^0	0^0
Cast Iron, Gray	-6^0-- 0^0	0^0	5^0
Copper	18-25^0		16^0
PVC	20-25^0		
Stainless Steel	8^0- 10^0	8^0	8^0
Steel, Mild	12-14^0	20^0	8^0-15
Titanium	0^0-4^0		

The rake angle is most important angle in manufacturing operation. However, there are back rake and side rake angles and out of these two-side racks is most influential as it is the direction of cut. As we know insert with negative rake angle can withstand much larger force then positive rake angle. However, negative rake has certain disadvantages, it requires more horsepower and maximum and maximum machine rigidities. That shows, more GHG emissions. It is more difficult to achieve good surface finish. It is advised that positive rake angle should be selected only if negative rake angle cannot do the job. Negative rake also reduces the longitudinal force (direction of feed) on the workpiece. The nose radius of the insert has great influence on the metal cutting process. The first it provides strength to the tip of the tool. The larger the nose radius the better is life of the tip of tool. It has also affect on the surface finish of the work material. A primary used model for estimating the surface roughness value is:

$R_i = \frac{f^2}{32\,r}$. , where Ri is ideal or theoretical surface roughness, f is feed (in/rev) , and r is tool nose radius in inches. The real or actual surface is estimated to be higher than the theoretical surface roughness.

Strategies to reduce energy demand in metal working processes are becoming necessary due to the growing concern of carbon dioxide (CO2) emissions and the expected rise of electricity prices over time. To move the development ofmetalworking the combination of metal workpiece and cutting should be selected smartly and sustainably. The simulation carried out in this article present approach how to find a winning combination for a sustainable metal working or manufacturing and reduce GHG emissions. An analysis of design of cutting tool to reduce energy consumption is presented including the material combination. It has been presented in literature that approximately 19 % of the climate greenhouse gas is emitted by manufacturing industries and out of that Us contributes about 31%. Some of the key properties required for cutting tools to machine for environmentally conscious manufacturing or cutting of work materials include: i) High hot hardness, i.e., retention of the cutting edge at elevated temperatures near the tool/workpiece interface, ii) Ability to withstand high cutting forces during machining, iii) ow thermal conductivity to resist edge degradation such as depth-of-cut notching, plastic deformation, and oxidation caused by high temperatures at the cutting edge, iv) Chemical inertness to minimize formation of built-up edge (BUE) and the possibility of coating delamination, v) High wear resistance to reduce abrasive wear at the cutting edge due to hard intermetallic compounds in the microstructure, vi) Geometry that provides efficient cutting, good chip-breaking, and minimizes heat generation during machining to reduce subsurface defects on the work piece.

2. Example

A Table of materials and cutting tool material with their rake angles are presented in the Table 2 below for investigation in this article.

Table 2: Work material and Cutting tool materials with their rake angles

Work material		High Speed Steel	Cemented Carbide	
class	Hardness (BHN)	HSS	Brazed	Throwaway
Aluminum	30-150	$-9 \leq \alpha \leq 20$	$-12 \leq \alpha \leq 3$	$-6 \leq \alpha \leq 0$
Cast iron	110-200	$-4 \leq \alpha \leq 5$	$-12 \leq \alpha \leq 0$	$-12 \leq \alpha \leq -5$
Steel	85-225	$-5 \leq \alpha \leq 10$	$-4 \leq \alpha \leq 0$	$-6 \leq \alpha \leq 0$

3. Analysis

We want to decide about the work material and cutting tool combination for minimum CO_2 emission but calculate most of the GHG gases emitted in air. The cutting forces during metal removal operations are well established and they are used to estimate the power requirement during metal removal operation. $F_c = \frac{S \times t_o \times w \times \cos(\beta-\alpha)}{\sin\emptyset \times \cos(\emptyset+\beta-\alpha)}$, Power calculation is based on F_cxV. The power requirement then is used to calculate the greenhouse gas (GHG) emissions in air. However, GHG emissions will depend on the combination's energy sources used in the grid. However, the results presented below are based on US grid. The force equations for cutting force (F_c), (thrust force (F_t), Shear force (F_s) and friction force (F) are calculated by a program written on MATLAB platform and cutting is used to calculate the power requirement in HP and then the following relations provided by Gutowski [ ] are used to calculate the GHG emissions. The Us Energy production by sources are; Hydro-7.1%, Nuclear-19.65, Coal-50.1%, Gas-16.7%, Oil-3%, Renewable Energy-2.27%. The transmission line efficiency in Us grid is only about 30% and we can imagine the efficiency of other less technologically developed countries. It only means that if we are using 1 MWH at the plant actually it is equivalent to 3 MWH at the generation point and the GHG emissions should be estimated at the plant. The electricity from US grid comes with 667 kg of CO_2/MWh, 2.75 Kg of SO_2/MWh, 1,35 Kg of NO_x/MWh, and 12.3 g of Hg/MWh. These data are taken from US Energy Information Administration DOE 2002 [1] Gutoski [4)]. These data are used in estimation of GHG in this article. The results are presented in tables below. Aluminum Vs HSS, Cast Iron Vs. HSS, and Steel Vs. HSS. For Every Cutting tool material, the results for three work materials are presented. It means total 9 results are presented in 9 tables below.

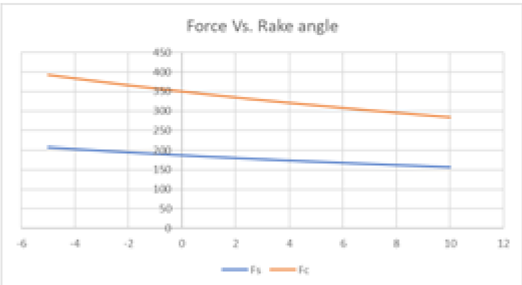
Table 3: Power & GHG Emissions for HSS Tool, Aluminum

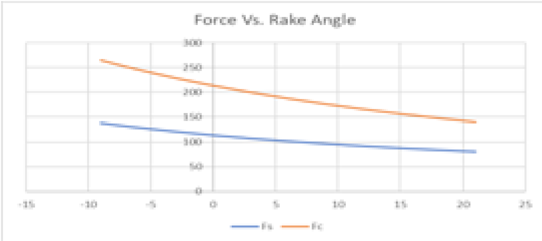
Rake	-9	-6	-3	0	3	6	9	12	15	18	21
radians	-0.15	-0.1	-0.052	0	0.052	0.105	0.157	0.209	0.268	0.31	0.37
Fs (lbf)	138	129	121.1	114	107.7	102	96.93	92.35	88.21	84.45	81
Beta (degrees)	46.9	47.45	47.93	48.39	48.81	49.22	49.61	49.98	50.33	50.68	51
Fc (lbf)	264.3	245.2	228.3	213.2	199.6	187.3	176.1	166	156.7	148.2	140.4
Shear Power, hp	1.51	1.4	1.301	1.212	1.131	1.057	0.988	0.925	0.867	0.812	0.76
Cutting Power (hp)	2.6285	2.438	2.269	2.119	1.983	1.861	1.751	1.65	1.558	1.473	1.39
Total Power (hp)	4.1395	3.839	3.571	3.331	3.115	2.918	2.739	2.575	2.425	2.285	2.16
CO2 Emission (kg)	6.2391	5.786	5.383	5.021	4.695	4.399	4.129	3.882	3.655	3.445	3.25
SO2 Emission (kg)	0.0257	0.023	0.022	0.02	0.019	0.018	0.017	0.016	0.015	0.014	0.01
NOx Emission (kg)	0.012	0.011	0.01	0.01	0.009	0.008	0.008	0.007	0.007	0.006	0.01
Hg Emission (kg)	0	0	9.93E-05	9.26E-05	8.66E-05	8.12E-05	7.62E-05	7.16E-05	6.74E-05	6.36E-05	6.00E-05

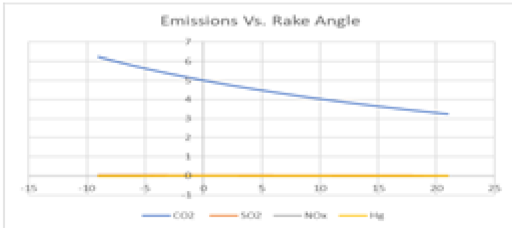
Table 4: Power and GHG Emissions for HSS Tool, Cast Iron Material

Rake angle	-4	-1	2	5
Rake angle (radians)	-0.06981	-0.01745	0.034907	0.087266
Fs (lbf)	89.05837	83.73049	78.99392	74.76356
Beta (degrees)	47.7748	48.23812	48.67454	49.08732
Fc (lbf)	168.2984	156.9776	146.8296	137.6849
Gamma	3.312571	3.083171	2.874973	2.68493
Shear Power (hp)	0.960337	0.893833	0.833475	0.77838
Cutting Power ,hp	1.673212	1.560661	1.459771	1.368855
Total Power (hp)	2.63355	2.454494	2.293246	2.147235
CO2 Emission (kg)	3.97093	3.700946	3.457812	3.237653
SO2 Emission (kg)	0.016372	0.015259	0.014256	0.013349
NOx Emission (kg)	0.008037	0.007491	0.006999	0.006553
Hg Emission (kg)	7.32E-05	6.82E-05	6.38E-05	5.97E-05

Place results and discussion here. *Authors should make sure that all tables, graphics, and equations fit within the columns and do not run into the margins.* All figures, graphs, tables, etc.







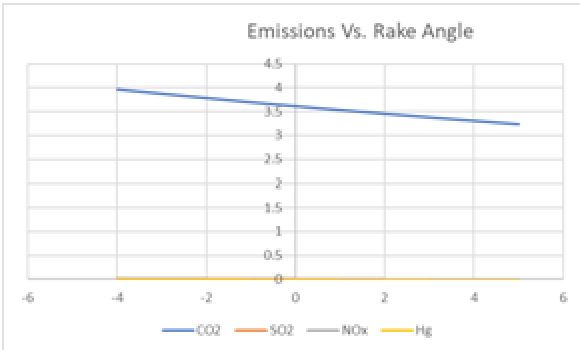
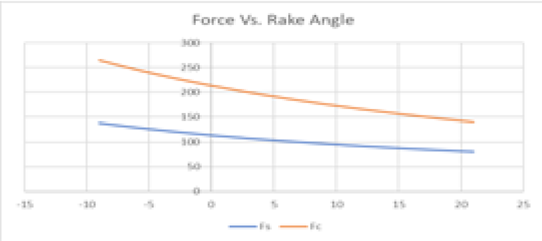


Table 5: Power &GHG Emissions for HSS &Steel Material

Rake angle	-12	-9	-6	-3	0	3
Rake angle (radians)	-0.20944	-0.15708	-0.10472	-0.05236	0	0.05236
Fs (lbf)	148.6627	138.261	129.1521	121.126	114.0146	107.6823
Beta (degrees)	46.38231	46.93379	47.44934	47.93243	48.38642	48.8146
Fc (lbf)	286.0794	264.3926	245.2756	228.309	213.1579	199.5519
Gamma	4.059282	3.752554	3.479093	3.233534	3.011579	2.809742
Shear Power (hp)	1.634464	1.51096	1.400852	1.301978	1.212608	1.131338
Cutting Power ,hp	2.844184	2.628575	2.438515	2.269834	2.119203	1.983932
Total Power (hp)	4.478648	4.139535	3.839366	3.571812	3.331811	3.115271
CO2 Emission (kg)	6.750298	6.239181	5.786762	5.383499	5.021765	4.695392
SO2 Emission (kg)	0.027842	0.025734	0.023868	0.022205	0.020713	0.019367
NOx Emission (kg)	0.013668	0.012633	0.011717	0.010901	0.010168	0.009507
Hg Emission (kg)	0.000125	0.000115	0.000107	9.93E-05	9.26E-05	8.66E-05

Table 6: Power & GHG Emissions for Brazed &Al,

Rake angle	-5	-2	1	4	7	10
Rake angl(radians)	-0.08727	-0.03491	0.017453	0.069813	0.122173	0.174533
Fs (lbf)	207.2394	194.6043	183.39	173.389	164.4317	156.3782
Beta (degrees)	47.61381	48.08683	48.53185	48.95215	49.35099	49.73165
Fc (lbf)	392.6146	365.8372	341.8788	320.3257	300.84	283.1432
Gamma	3.394371	3.157114	2.942217	2.746425	2.567064	2.401922
Shear Power (hp)	2.241451	2.08478	1.942874	1.813584	1.695144	1.586094
Cutting Power hp	3.903351	3.637131	3.398938	3.184659	2.990933	2.814993
Total Power (hp)	6.144802	5.721911	5.341812	4.998243	4.686078	4.401087
CO_2 Emission (kg)	9.265282	8.627636	8.054514	7.536472	7.065781	6.636065
SO_2 Emission (kg)	0.0382	0.035571	0.033208	0.031072	0.029132	0.02736
NO_x Emission (kg)	0.018753	0.017462	0.016302	0.015254	0.014301	0.013431
Hg Emission (kg)	0.000171	0.000159	0.000149	0.000139	0.00013	0.000122



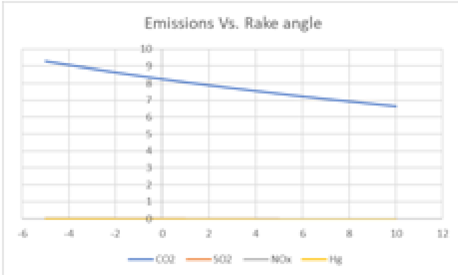
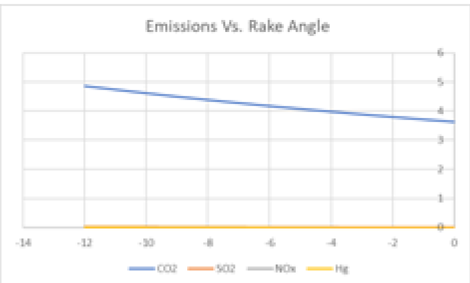
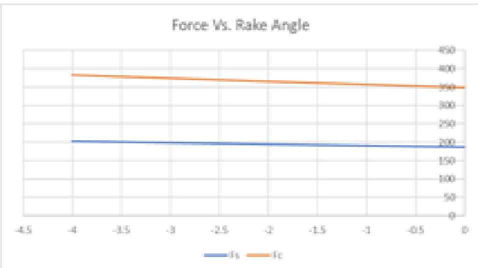
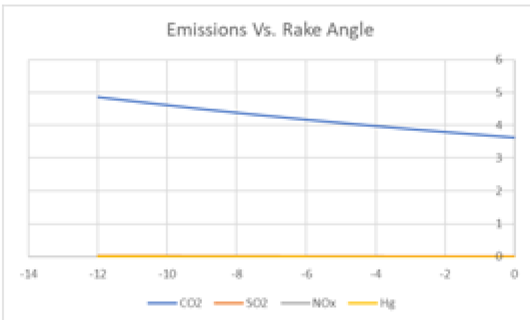


Table 7: Power & GHG Emissions for Brazed Vs CI

Rake angle	-12	-9	-6	-3	0	3
Rake angle (radians)	-0.20944	-0.15708	-0.10472	-0.05236	0	0.05236
Fs (lbf)	148.6627	138.261	129.1521	121.126	114.0146	107.6823
Beta (degrees)	46.38231	46.93379	47.44934	47.93243	48.38642	48.8146
Fc (lbf)	286.0794	264.3926	245.2756	228.309	213.1579	199.5519
Gamma	4.059282	3.752554	3.479093	3.233534	3.011579	2.809742
Shear Power (hp)	1.634464	1.51096	1.400852	1.301978	1.212608	1.131338
Cutting Power ,hp	2.844184	2.628575	2.438515	2.269834	2.119203	1.983932
Total Power (hp)	4.478648	4.139535	3.839366	3.571812	3.331811	3.115271
CO_2 Emission (kg)	6.750298	6.239181	5.786762	5.383499	5.021765	4.695392
SO_2 Emission (kg)	0.027842	0.025734	0.023868	0.022205	0.020713	0.019367
NO_x Emission (kg)	0.013668	0.012633	0.011717	0.010901	0.010168	0.009507
Hg Emission (kg)	0.000125	0.000115	0.000107	9.93E-05	9.26E-05	8.66E-05







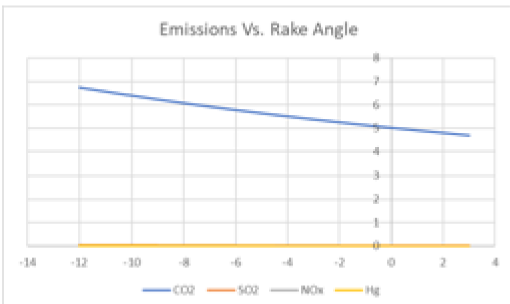
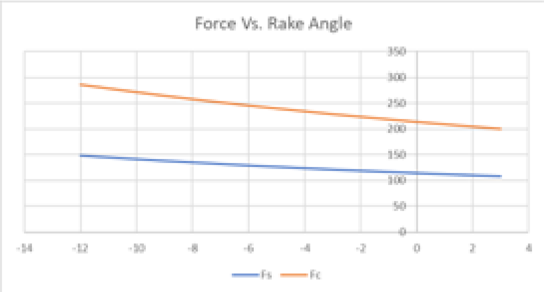
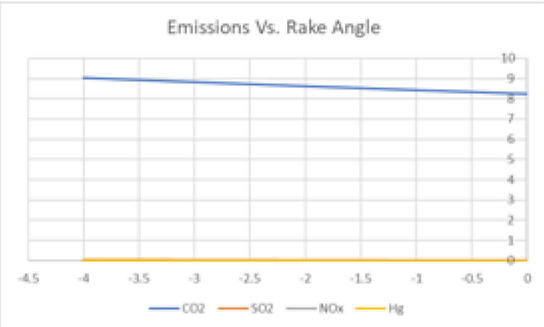
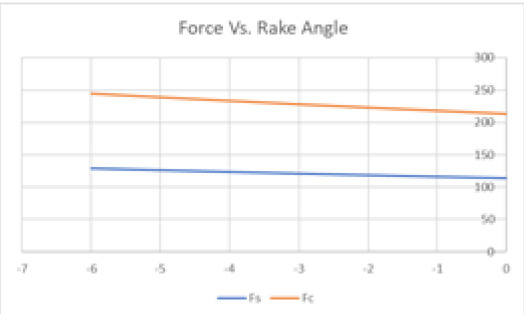


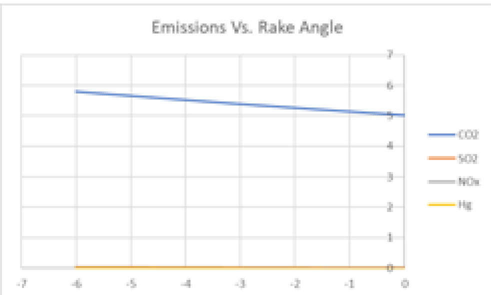
Table 8: Power & GHG Emissions for Brazed Vs Steel

Rake angle	-4	-3	-2	-1	0
Rake angle (radians)	-0.06981	-0.05236	-0.03491	-0.01745	0
Fs (lbf)	202.8552	198.6466	194.6043	190.7194	186.9839
Beta (degrees)	47.7748	47.93243	48.08683	48.23812	48.38642
Fc (lbf)	383.3463	374.4268	365.8372	357.56	349.5789
Gamma	3.312571	3.233534	3.157114	3.083171	3.011579
Shear Power (hp)	2.187435	2.135244	2.08478	2.035952	1.988677
Cutting Power (hp)	3.811206	3.722528	3.637131	3.55484	3.475493
Total Power (hp)	5.998641	5.857772	5.721911	5.590792	5.46417
CO2 Emission (kg)	9.044896	8.832491	8.627636	8.429932	8.239007
SO2 Emission (kg)	0.037292	0.036416	0.035571	0.034756	0.033969
NOx Emission (kg)	0.018307	0.017877	0.017462	0.017062	0.016676
Hg Emission (kg)	0.000167	0.000163	0.000159	0.000155	0.000152









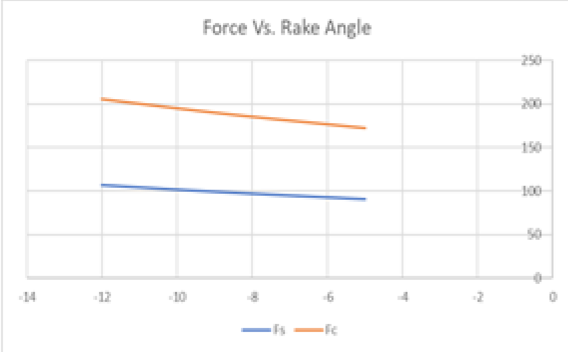


Figure 1: Percentage of papers TH

Table 7: Power & GHG Emissions for Brazed Vs steel

Rake angle	-12	-9	-6	-3	0
Rake angle (radians)	-0.20944	-0.15708	-0.10472	-0.05236	0
Fs (lbf)	107.0372	99.54793	92.98954	87.2107	82.09049
Beta (degrees)	46.38231	46.93379	47.44934	47.93243	48.38642
Fc (lbf)	205.9772	190.3626	176.5984	164.3825	153.4737
Gamma	4.059282	3.752554	3.479093	3.233534	3.011579
Shear Power (hp)	1.176814	1.087891	1.008613	0.937424	0.873078
Cutting Power, hp	2.047812	1.892574	1.755731	1.634281	1.525826
Total Power (hp)	3.224626	2.980465	2.764344	2.571705	2.398904
CO2 Emission (kg)	4.86217	4.494018	4.168145	3.877679	3.617125
SO2 Emission (kg)	0.020046	0.018529	0.017185	0.015987	0.014913
NOx Emission (kg)	0.009841	0.009096	0.008436	0.007848	0.007321
Hg Emission (kg)	8.97E-05	8.29E-05	7.69E-05	7.15E-05	6.67E-05

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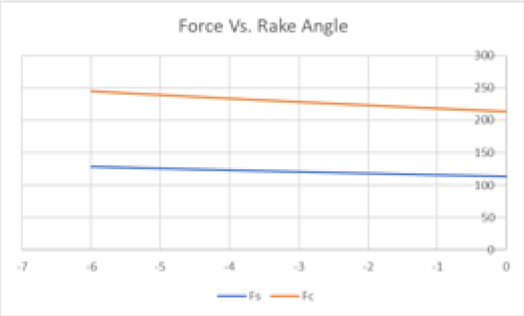
Table 9: Power & GHG Emissions, Throwaway Vs Aluminum

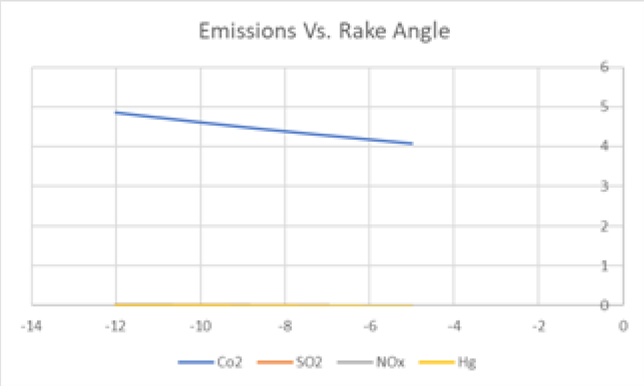
Rake angle	-6	-3	0
radians	-0.10472	-0.05236	0
Fs (lbf)	129.1521	121.126	114.0146
Beta (degrees)	47.44934	47.93243	48.38642
Fc (lbf)	245.2756	228.309	213.1579
Gamma	3.479093	3.233534	3.011579
Shear Power (hp)	1.400852	1.301978	1.212608
Cutting Power, hp	2.438515	2.269834	2.119203
Total Power (hp)	3.839366	3.571812	3.331811
CO2 Emission (kg)	5.786762	5.383499	5.021765
SO2 Emission (kg)	0.023868	0.022205	0.020713
NOx Emission (kg)	0.011717	0.010901	0.010168
Hg Emission (kg)	0.000107	9.93E-05	9.26E-05

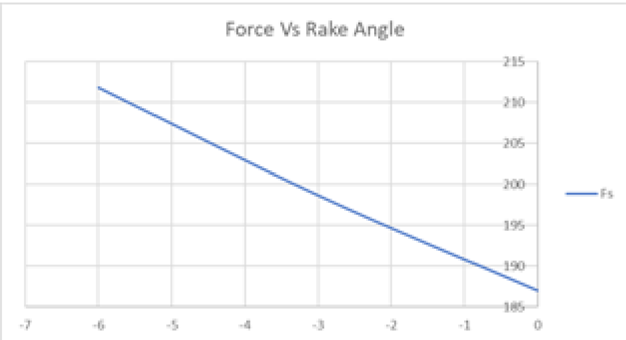
Table 10: Power & GHG Emissions for Throaway Vs CI

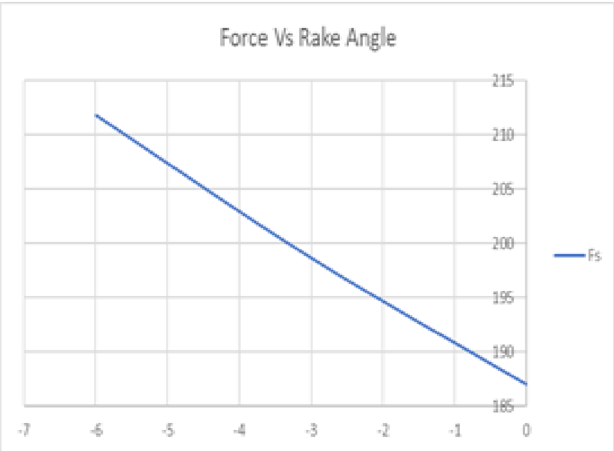
Rake angle	-12	-10	-8	-5
radians	-0.20944	-0.17453	-0.13963	-0.08727
Fs (lbf)	107.0372	101.9324	97.26656	90.98316
Fc (lbf)	205.9772	195.3449	185.5853	172.3674
Gamma	4.059282	3.850799	3.657994	3.394371
Shear Power (hp)	1.176814	1.116373	1.060478	0.984052
Cutting Power ,hp	2.047812	1.942107	1.845078	1.713666
Total Power (hp)	3.224626	3.05848	2.905556	2.697718
CO2 Emission (kg)	4.86217	4.611651	4.381068	4.067685
SO2 Emission (kg)	0.020046	0.019014	0.018063	0.016771
NOx Emission (kg)	0.009841	0.009334	0.008867	0.008233
Hg Emission (kg)	8.97E-05	8.50E-05	8.08E-05	7.50E-05

Paper ID: SR21704195515 DOI: 10.21275/SR21704195515









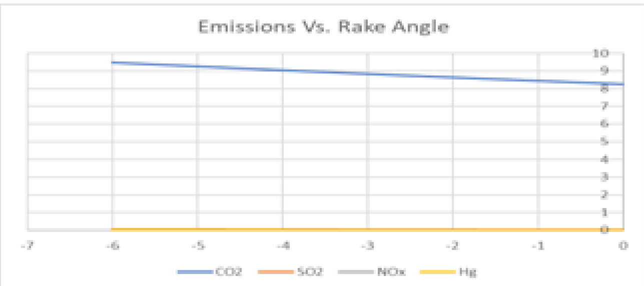


Table 11: Power & GHG Emissions for Throwaway Vs Steel

Rake angle	-6	-3	0
radians	-0.10472	-0.05236	0
Fs (lbf)	211.8095	198.6466	186.9839
Shear Power (hp)	2.297397	2.135244	1.988677
Cutting Power hp	3.999164	3.722528	3.475493
Total Power (hp)	6.296561	5.857772	5.46417
CO2 Emission (kg)	9.494107	8.832491	8.239007
SO2 Emission (kg)	0.039144	0.036416	0.033969
NOx Emission (kg)	0.019216	0.017877	0.016676
Hg Emission (kg)	0.000175	0.000163	0.000152

$$x = \frac{-b \pm \sqrt{b^2-}}{2a} \qquad (1)$$

Table 12: Average GHG Emissions for Tools vs. an Aluminum

Aluminum	HSS	CC Brazen	CC Throwaway
Average CO2 (Kg)	4.5325	5.64149	5.39734
Average SO2 Emission (kg)	0.01871	0.023288	0.022262
Average NOx Emission (kg)	0.00918	0.0114323	0.0109286
Average Hg Emission (kg)	8.37E-05	0.00010416	9.96E-05

Table 13: Average GHG Emissions for Different Tools vs. a Cast Iron Material

Cast Iron	HSS	CC Brazen	CC Throwaway
Average CO2 Emission (kg)	4.62301	4.2038	4.4806
Average SO2 Emission (kg)	0.019068	0.017332	0.01847
Average NOx Emission (kg)	0.0093606	0.008508	0.009068
Average Hg Emission (kg)	8.52864E-05	7.75E-05	8.26E-05

Table 14: Average GHG Emissions for Different Tools vs. a Steel Material

Steel	HSS	Brazen	Cemented Carbide Throwaway
Average CO2 Emission (kg)	7.8643	8.6348	8.8552
Average SO2 Emission (kg)	0.03242	0.0356	0.03651
Average NOx Emission (kg)	0.015917	0.017476	0.01792
Average Hg Emission (kg)	0.000145	0.0001592	1.63E-04

Information about the three work materials, aluminum, cast iron, and steel, were represented to show how cutting speeds and tool material combinations effect the greenhouse emissions (GHG) and the power consumption of orthogonal turning operations. However, in the manufacturing operation, other factors, such as tool life and surface finish, that must be considered in the selection for the appropriate tool material corresponding to the work piece. It is also necessary to improve the machining process by limiting the greenhouse gases and power consumption during the operation. Failure to do so could result in a machining operation that consumes too much power and releases large amounts of greenhouse gases (GHG). Furthermore, these conditions lower the performance of machining and should be avoided. Other possibilities occur from conditions in which have a high-power consumption that should be considered when selecting a material for the tool in the turning operation.

The information provided listed three work materials of which were to be inspected against two turning materials; high speed steel and cemented carbide. Each of the different tool materials had different rake angles associated with their corresponding workpiece. Below in Table 15 lists all of the materials to be tested and their corresponding rake angles.

As shown in the table, each of the rake angles listed are given in intervals with negative valued angles. However, by proof of how rake angles effect forces and CO2 emissions, it was concluded that negative valued rake angles are discouraged as they produce relatively high values for machining forces, power consumption, and CO2 emissions produced. Therefore, for the purpose of this inspection, the highest value of the rake angle listed for each of the work materials were only considered to show how cutting speeds change the CO2 emissions and power consumption. This is shown to be true by the conclusion of how negative rake angles produce unfavorable manufacturing conditions and it is always favorable to have the largest possible rake angles, as these conditions produce the least amount of emissions and power consumption. Thus, the following statement is justified.

Starting with aluminum and comparing it with a high-speed steel cutting tool, if it is true that non-steel metals have feeds and depths of 0.25 mm and 2.5 mm, then for aluminum and cast iron, it can be concluded that the feed and depth of cut of the turning operation are 0.25 mm and 2.5 mm respectively. These are accepted values for which a typical turning operation consisting of non-steel tooling materials will have these values for the feed and depth of cut. Furthermore, if it true that the conversion of turning and the orthogonal cutting model suggest that the chip thickness is the feed for turning, and the width of cut is the depth of cut for turning, then these values (the feed and depth of cut) can be used to determine the machining forces that occur during the operation. Also, by observation of a turning operation, as the cylindrical workpiece rotates, the cutting tool is inserted into the material to be removed while the workpiece rotates. One can see by inspection that the plane that is present at the tip of the cutting tool is the same shear plane that forms in the orthogonal cutting model; further proving that this conversion is true. Likewise, the depth of cut is equivalent to the width of cut on the orthogonal cutting model by observation. Below in Figure 1 an example of this phenomenon. Another statement about the machining forces can be said to provide further understanding of the turning operation. For instance, it is true that there are many forces that occur during the cutting operation, like friction force between the chip face and the tool face, and shear force that occurs on the shear plane. However, during the turning operation if the shear force and the cutting force show favorable conditions such that the operation will be successful, then it is concluded that all the other forces will also have favorable conditions, as these two forces are the strongest forces responsible for the turning operation. In other words, if the cutting and shear force are favorable then the machining operation will be successful. The statements mentioned about the turning operation are true, regardless of the material/tool combination. Such statements can be used to investigate various turning operations. We were able to calculate hot hardness of all cutting tool materials using Groover [13] equation. The maximum temperature during machining of different materials for HSS cutting tool material at different rake angles was estimated to be below 600^0C and for cemented carbide were below 800^0 C. These estimations showed that tools were able to keep its sharpness during machining operations at different rake angles. The surface roughness calculations for all three cutting tool material were also studied. The tool nose radius was kept at 1.2 µm and feed was also fixed at 0.25 mm/rev. The surface for all three types of cutting tools and work materials differed widely. Almost there nine combinations of work materials and cutting tools and surface roughness were in the range 1.8 µm to 2.7 µm. This may reflect that we did not change the cutting speed. However, the simulation showed that selection of cutting tools for different materials were reasonable.

4. Conclusion

After reviewing the average GHG emissions for each combination of material and tool, it can be determined that the best combination is Cast Iron and a cemented carbide brazen tool. (Table 11). This combination has the lowest CO2 emission. Furthermore, it has the lowest SO2, and NOx emissions as well. It does not have the lowest Hg emission, but it is one of the lowest on the list. Considering all of these factors it makes sense to choose this combination.

Based on the GHG emissions of each combination of work and tool material considered the best option was found. The least harmful and therefore the best combination of materials was, high speed steel for the tool material, when using Aluminum as the work material.

Based on the GHG emissions of each combination of work and tool material considered the best option was found. The least harmful and therefore the best combination of materials was, Braised Cemented Carbide for the tool material, when using Cast Iron as the work material.

Based on the GHG emissions of each combination of work and tool material considered the best option was found. The least harmful and therefore the best combination of materials was, high speed steel for the tool material, when using Steel as the work material.

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