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Coolant fluid in a turning operation: Soybean coolant fluid in different concentrations versus petroleum coolant fluid

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COOLANT FLUID IN A TURNING OPERATION:

SOYBEAN COOLANT FLUID IN DIFFERENT CONCENTRATIONS

VERSUS PETROLEUM COOLANT FLUID

An Abstract of a Thesis

Submitted

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

Mary Esther Eckman

University of Northern Iowa

July 2012

ABSTRACT

The manufacturing sector today's market felt the need to reduce costs along with the ability to be more "green."

Traditionally petroleum based fluids are used in the manufacturing industry. However they are environmentally more harmful as well as cause significant hazards to the operator. This thesis will provide a case study for this sector to become more environmentally friendly with the use of a soybean based cutting fluid. To prove the point a number of tests were performed turning 4140 steel on a CNC turning center. A number of tests were conducted to provide a comparative study of dry, petroleum based cutting fluid and soybean based cutting fluid at different concentrations.

It has been found that the soy based cutting fluid is just as good as the petroleum product when done at the same concentration which is recommended by the manufacturer. However increasing the concentration of the fluid compared to the suggestion of the manufacturer provided an improved machining performance based on the measured characteristics.

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has been approved as meeting the thesis requirement for the

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7/19/12
Date Dr. Michael Licari, Dean, Graduate College

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CHAPTER 1

INTRODUCTION

The deterioration of the environment due to the use of petroleum based products and the costs of these products has made the development of alternative environmental safe products come to light. Public support along with government input has made the industrial sector look at the agriculture markets as an alternative. The instable cost of petroleum has also contributed to the need for change, and with no stability in the petroleum market in sight in the near or far off future, the search for alternatives will become necessary. As a result of these needs, many crop based fluids are being developed and being used as lubricants, solvents and resins just to highlight a few. Vegetable oils have many qualifications that are useful in the industrial setting. They have been cited to be low toxicity toward persons, and biodegradable coming from renewable resources (Bramlet, 2007).

Soybean oil has many applications in industry. The application in the coolant/cutting fluid in machining in a turning center is just one of the uses. It is important that studies be performed to determine if the soy oil is a good alternative for the petroleum product. Without these studies, the benefits of the biodegradable fluid cannot be determined (Fang, 2011).

The present study being performed is a comparison of soy oil in concentrations of 4%, 8%, and 12% to petroleum fluid in the manufacturer suggestion of 8%. The determination of tool wear is measured to see if the petroleum is better, not as good or just as good to the soy oil in the different concentrations (Zhou, 2010).

Statement of Purpose

The purpose of this study is to explore the effects of the use of soybean oil being used as a coolant/cutting fluid in a turning center on tool wear.

Statement of Problem

The problem that this study will help to determine a solution for is the cost that is evident in the use of soy oil versus petroleum. The question of cost will not be discussed within this study, but will become useful in an economic study of the process.

Statement of Need

Different studies need to be done to determine if soy oil can be used as a viable solution to the uses of petroleum products in the industrial area of science. This solution will take in to account the use of the soy oil in the coolant/cutting fluid to include tool wear, disposal of spent oil and possibility of reducing costs in the metal cutting operation.

The soy oil, being biodegradable, should be considered environmentally safe. The contamination that is caused by the use of petroleum oil on the environment should be lessened if not eliminated with the use of the soy oil. By using the soy oil, there will be less if not any disposal of spent fluid, hence reduction of cost.

The soy oil used in this study is emulsified in water that when mixed at certain concentrations works well as a coolant/cutting fluid. The petroleum oil is also emulsified in water so the comparison is done as closely as possible with the manufactures recommendation on both solutions. The varying of the concentrations in the soy oil emulsion is to determine if a different concentration performs better than the petroleum mixture.

It has been shown that the heat produced during machining has an impact on the tool wear. The use of coolant/cutting fluid has been shown to have positive effects on the metal being used and the tool, in the machining process.

The coolant/cutting fluid is used during a turning operation to reduce friction and minimize the heat created by the process. The heat being created in the process has a high degree and the coolant/cutting fluid plays the part of reducing the heat and pulls it away from the metal work piece.

Soy oil is considered a biological resource, grown in large qualities in the United States and welcoming to future uses.

Statement of Hypothesis

Hypothesis 1: The null hypothesis, H_{01} is that there are no differences between soy oil and petroleum oil on dependant variables (tool wear). This will be studied at different treatments including speeds along with diverse concentrations. The alternative hypothesis 1, H_{a1} is that there are significant differences when using the soy oil and the petroleum oil.

Assumptions

1. The assumption is that all the inserts/tools have the same characteristics.
2. The assumption is that the metal being used for all experiments is 4140 carbon steel.
3. The assumption is that all tool used for measuring have been properly calibrated.
4. The assumption is that the feed rates and speeds are true.
5. The assumption that the percent of the fluid concentration is accurate.

Limitations

1. The only material being used for the study is 4140 steel rod in a diameter of 6 inches in the turning operation.
2. The cutting tools used in the experiments are Kennametal CNMG432.
3. The type of petroleum oil used is a Castrol Clearedge 6510.
4. The type of soy bean oil used is a plain mixture with no additives.
5. All tools will be measures on a toolmakers microscope and recorded.

CHAPTER 2

LITERATURE REVIEW

As more stringent environmental legislation is enforced throughout Europe manufacturing businesses, employing metal cutting processes can no longer ignore the growing importance of environmental aspects relating to cutting fluids. Businesses, through market forces, are being forced into offering a “clean solution” to the metal cutting processes which they operate. Cutting fluids despite playing an important role in metal cutting have considerable environmental impact. There is a need therefore to understand the role of cutting fluids within the cutting process in order to evaluate possible environmentally friendly alternatives to the use of cutting fluids. In order to achieve this the operating environment in which the process is being carried out, and the consequences of removing the cutting fluid from the process altogether has to be assessed. This paper therefore, reflects on the role of cutting fluid and the implications of their use. Viable methods of reducing cutting fluid consumption are also reported, together with efficient methods of cutting fluid utilisation (e.g. minimum quantity delivery systems). Finally, the difficulties experienced in removing cutting fluids from the metal cutting process are highlighted through the consideration of dry cutting technologies (Lister, 2002).

Green machining of P/M parts has been actively studied in recent years. The advantages have been well recognized, including longer cutting tool life and the ability to make complex parts out of sinter- hardenable powders. The high green strength of the compacted parts also prevents green cracks and damages from handling (Danaher, 2002).

Most green machining operations have been limited to warm compacted parts. However, this limitation is being removed with a newly developed high green strength (HGS) polymeric lubricant. One distinguished

characteristic of this lubricant is its ability to provide high green strength at a compacting temperature of ~55°C, which can be easily reached by cold compaction. Even higher green strength up to ~7000 psi (48 MPa) can be achieved by a subsequent curing process for parts pressed to a density of 6.8 g/cm3. This high green strength has made green machining possible for those parts fabricated through conventional P/M processes (Danaher, 2002).

This paper presents the results of green machining tests performed on timing sprockets. The material used was a sinter-harden able powder mix of ATOMET 4601 and the HGS lubricant. The sprockets were pressed to a density of ~6.8 g/cm3 by cold compaction. Green machining, which consists to turn a groove along the middle of the teeth, was performed on as-compacted and on cured parts (Danaher, 2002).

The use of vegetable oils and animal fats for lubrication purposes has been practiced for many years. With the discovery of petroleum and the availability of inexpensive oils, alternatives became unattractive and were left by the wayside. Attention was refocused on vegetable oils during wartime and oil shortage situations. For example, during World War I and World War II, the use of vegetable oils for fuel, lubricants, greases and energy transfer increased rapidly. Also, the oil embargo of 1973 brought needed attention to alternatives for petroleum oils (Honary, 2006).

Over the past two decades, a renewed interest in vegetable oil-based lubricants has occurred as environmental interest has increased. In Europe during the 1980s, various mandates and regulations were placed on petroleum products necessitating the use of biodegradable lubricants. During the 1990s, many American companies began developing biodegradable products. A prime example is when the Mobil Corporation introduced its Environmental Awareness Lubricants (EAL) line of hydraulic fluids. The Lubrizol Corporation also developed considerable quantities of additives and sunflower oil-based lubricants. However, the lack of regulatory mandates in the United States, as well as the availability of post-Desert Storm low cost oil, made biodegradable oils too expensive to compete (Honary, 2006).

The next decade will recognize more advances in the use of biodegradable lubes and greases than in any other time in history. There are at least three major reasons for this upbeat prediction: Patterning after European farmers, U.S. growers' associations have begun spending considerable sums of money on research in nonfood "new uses" areas to reduce crop surpluses (Honary, 2006).

The federal government has introduced initiatives to promote the use of environmentally friendly products within federal agencies (Honary, 2006).

There have been advancements in biodegradable lubricants technology and genetic enhancement to seed oils (Honary, 2006).

The paper proposes a method to obtain reliable measurements of tool life in turning, discussing some aspects related to experimental procedure and measurement accuracy. The method (i) allows an experimental determination of the extended Taylor's equation, with a limited set of experiments and (ii) provides a basis for the quantification of tool life measurement uncertainty. The procedure was applied to cutting fluid efficiency evaluation. Six cutting oils, five of which formulated from vegetable base stock, were evaluated in turning. Experiments were run in a range of cutting parameters, according to a 23–1 factorial design, machining AISI 316L stainless steel with coated carbide tools. Tool life measurements were associated to an estimation of their uncertainty, and it was found that by taking three repetitions the uncertainty calculated with a coverage factor of two was on average three times bigger than the experimental standard deviation (Dragos, 2001).

An analysis of cutting fluid performance in different metal cutting operations is resented, based on experimental investigations in which type of operation, performance criteria, work material, and fluid type are considered (De Chiffre, 2004).

Cutting fluid performance was evaluated in turning, drilling, reaming and tapping, with respect to tool life, cutting forces and product quality (dimensional accuracy and surface integrity). A number of different work materials were considered, with emphasis on austenitic stainless steel, and cutting fluids from two main groups, water miscible and straight oils, were investigated. Results show that correlation of cutting fluid performance in different operations exists, within the same group of cutting fluids, in the case of stainless steel as work piece material. Under the tested conditions, the average correlation coefficients between efficiency parameters with different operations on austenitic stainless steel laid in the range 0.87-0.97 for water based fluids and 0.79-0.89 for straight oils. A similar correlation could not be found for the other work piece materials investigated in this work. A rationalization of cutting fluid performance tests is suggested (De Chiffre, 2004).

The higher price of soy oil coolant/cutting fluid can make some metal working businesses decide not to go green. If the price is right, going green makes sense. Many manufacturers have interest in using more environmentally safe, health-conscious "green" coolants and lubricants remains high, many shops may be put off by the initially higher price tags of the coolant technology, despite potential health benefits for workers and cost savings, such as extending tool life (Waurzyniak, 2012).

When you're discussing metal cutting fluids, remember that green isn't simply a marketing term. Metal cutting fluids are ubiquitous in machining, and almost every manufacturing professional has seen advertisements for "green" metal cutting fluids. Suppliers to manufacturers insist that environmentally responsible coolants and lubricants can function just as well as conventional products, without requiring extensive modification of the equipment now operating on your shop floor (Hogan, 2010).

The interaction among tool, chip, and work piece usually causes tool wear as well as other types of damage. The wear/damage mechanisms discussed in this paper are abrasion and attrition. All of them are directly influenced by temperature. It is worthy to mention that temperature, in machining, is directly related to the cutting speed (Diniz, 2010).

In the process of abrasion, the hard second phase in a work material can be constrained by the matrix phase, rolled along the interface or even broken into pieces while abrading the flank face of the tool. Both flank and crater wear may be generated by abrasion, but flank wear is more affected by abrasion, since the tool flank face rubs against a rigid element such as the work piece, while the contact between tool rake face and chip involves sliding and seizure/adhesion. The ability of the tool to resist abrasive wear is related to its hardness. The wear land caused by abrasion generally displays scratches parallel to the cutting direction (Diniz, 2010).

Attrition wear usually occurs at low cutting speeds, when material flow on the tool rake face is irregular and contact with the tool is less continuous. It can be described as a cyclical adhesion and removal of work piece/chip material from the tool, this also causes removal of tool particles. Under these conditions, microscopic particles of the tool are pulled out and dragged together with the material flow. The irregular material flow necessary for attrition wear to occur is caused by the sliding zone between chip and tool, by interrupted cutting, irregular depth of cut, and vibration. Areas worn by attrition have a rough appearance. Wear mechanisms are strongly influenced by the effects of temperature, especially the thermally activated ones. Thus, decreasing cutting temperature usually means increasing cutting tool life. One way to reduce cutting zone temperatures is the use of cutting fluids. However, the advantages of using cutting are very resistant to high temperatures (Diniz, 2010).

It is reported that in Germany alone in 1994 it was estimated that 350,000 tons of cutting fluids were processed and subsequently disposed of. The cost of purchasing and disposing coolant is about one billion German Mark (Anon,1994). It is also estimated that cutting fluids cost 7-17 per cent of the manufacturing cost of components when associated costs of monitoring, maintenance, health precautions and absenteeism are taken into account in the German automotive industry compared to the tool costs that are quoted as being 2 - 4 per cent. As a result, increasing emphasis is now being placed on the research that can lead to the reduction in the costs associated with the cutting fluids by way of reducing the costs of their disposal or reducing the volume used (Klocke & Eisenblatte,1997).

It is reported that in Japan the cost of purchasing coolant is about 29 billion Japanese Yen a year as per the Japan Lubricant Economy in 1984. The details of the cutting fluid consumption is as follows : 100,000 kiloLiter water-immiscible (disposal cost 35-50 Yen per liter), 50,000 kiloLiter water-soluble coolant without chlorine (disposal cost 300 Yen per liter), and 10,000 kiloLiter water-soluble coolant with chlorine (disposal cost 2250 Yen per liter). Based on the above figures, the estimated coolant disposal cost alone in Japan is about 42 billion Yen. The total coolant purchasing and disposal cost is about 71 billion Yen a year (Shaw, 2000).

CHAPTER 3

MATERIALS AND PROCESS

Research Design

Three sets of data will collected the first to be no coolant/cutting fluid (dry), to use as a base run. The second run will be using the soy bean oil in three concentrations, 4%, 8% and 12%. And the third will be using the petroleum oil at the manufacturer's suggested concentration. The next variable considered is the speed that the turning center (lathe) is operating at. The three speeds chosen are 300 fpm, 350 fpm and 400 fpm. All the different solutions make-up will be tested at all the speeds. The test is for tool wear and how it performs under the different conditions.

Material

The materials necessary for the experiment are:

1. Three pieces of 4140 steel rod, measuring 6 inches in diameter with a length of 9 inches.
2. 75 Kennametal CNMG432 inserts.
3. 5 gallons of Soyease® soy bean oil.
4. 5 gallons of Castrol Clearedge 6510 coolant/cutting fluid.
5. 1 Atago PAL-α refractormeter.
6. 1 box of ph test strips.

Experiment

The experiments were conducted using the hardware and software listed as follows:

- CNC Turning Center: Haas SL-20 (Haas Automation, Inc).
- Mitutoyo Toolmaker's Microscope with a magnification 15 was used for measuring flank wear that occurred on the flank face of an insert resulting from abrasive wear of the cutting edge against the machined surface. The wear can be read as small as 0.001mm. The microscope and a picture of a worn insert taken under the microscope are shown in Figure 1 and Figure 2.
- Microsoft Excel and JMP software packages for charting data and statistical analysis.

Figure 1. Microscope used for tool wear measurement

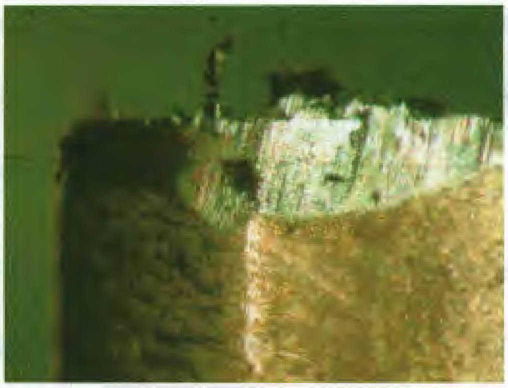

Figure 2. Flank wear example under microscope

The first step in preparation for the experiment was to have the program written for the CNC lathe. This was straight cut, 7 inches long on the piece of steel. The program also included the depth of cut which in this trial all were the same of .1 inch. The feed of the cutting tool was also programmed, and in the situation, all were the same a .015 ipr. The changing factor in the program was that the speeds changed from 300 fpr, to 350 fpr and 400 fpr. All these dominations are available in the Machinery's Handbook. To be used on 4140 steel.

The next step is the preparation of the coolant/cutting fluid. The tank on the CNC lathe is three quarters filled with water. The soy oil is then added to the water and mixed unto the concentration to the point needed for the experiment.

The tool is then inserted into the tool holder on the turret on the CNC lathe and secured. The billet of steel is then hoisted into the CNC lathe and chucked.

Following the directions on the CNC lathe, at this time you are setting the metal up to be turned, this included the position of the turret and tail stock and the mixing of the coolant/cutting fluid.

After the set-up of the experiment the power is turned on and the program is installed. The test is then performed and the insert is removed.

The insert is then placed on a tool maker's microscope and the tool wear is measured. This procedure is continued for the dry run, with adjustment to the program for speeds and diameter of metal piece.

The first run being the dry run, the concentration of the fluid does not need to be tested. This is only specific to the first 15 passes on this billet.

Once the passes are completed on the first billet, remove the metal piece from the turning center. A new billet is inserted just like in the first runs. This metal working material will be used for the soy oil concentrations. When the billet is secured, close door to the turning operation and press the coolant button. This will mix the coolant/cutting fluid and the water to become an emulsion.

Using the refractometer, measure the concentration of the soy oil and if more oil or water is needed, add and continue mixing to get to 4%. Continuing checking with refractormeter until concentration is correct. Repeat the steps for taking the measurement as described above, until 4% concentration is complete.

Once the 4% is done add more soy oil to get to the next level at 8% and then 12%.

When done with the soy oil, the reservoir that contains the liquid need to drained. This fluid is considered hazardous material, so it needs to dispose of by specific production laboratory instructions. The lab assistant will do the disposal after the drainage, not down the drain.

Start the procedure for the beginning where we had the dry material. Add the petroleum oil to the water to start the process. Mix the tank to have the petroleum oil and water to emulsify. Remove the insert and measure it and record the findings.

Data Collection

In the experiment, the work piece material AISI 4140 was prepared as Figure 3, 7 in. × 9 in. metal billets. It was chucked between the spindle chuck and the tailstock center in the Haas turning center as shown in Figure 3. One specific tool insert was used to turn and clean off the billet surface so as to make sure that all tested inserts would cut the clean work piece surface without any interference from rust or dirt. Figure 4 showed a copper tube connected to the cutting fluid orifice was directed to the insert and work piece to flood the interface of the work piece and the insert.

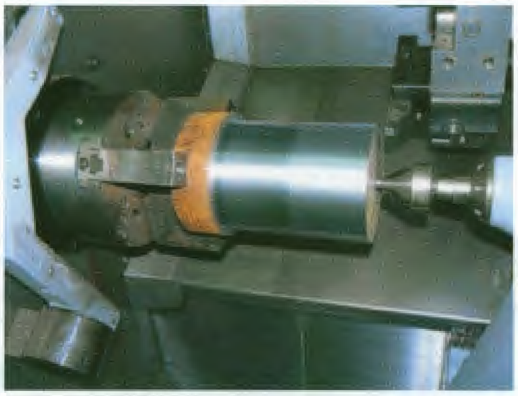

Figure 3. Work piece after one turning path

Figure 4. Cutting fluid applied to insert and work piece

Data

The following table is the result of the finding of the 75 passes.

Table 1
Data Collected

					Tool Wear				
Fluid	Concentration	Speed	Feed	Cut	Pass 1	Pass 2	Pass 3	Pass 4	Pass 5
Dry	None	300	0.015	0.1	0.412	0.433	0.526	0.501	0.456
Dry	None	350	0.015	0.1	0.436	0.487	0.498	0.527	0.478
Dry	None	400	0.015	0.1	0.555	0.565	0.597	0.578	0.489
Soy	0.04	300	0.015	0.1	0.295	0.322	0.301	0.338	0.345
Soy	0.04	350	0.015	0.1	0.356	0.344	0.349	0.363	0.321
Soy	0.04	400	0.015	0.1	0.388	0.379	0.366	0.392	0.326
Soy	0.08	300	0.015	0.1	0.281	0.265	0.271	0.214	0.255
Soy	0.08	350	0.015	0.1	0.219	0.226	0.299	0.354	0.234
Soy	0.08	400	0.015	0.1	0.274	0.203	0.226	0.221	0.231
Soy	0.12	300	0.015	0.1	0.111	0.123	0.117	0.125	0.174
Soy	0.12	350	0.015	0.1	0.162	0.177	0.144	0.213	0.104
Soy	0.12	400	0.015	0.1	0.237	0.100	0.139	0.137	0.155
Petro	0.08	300	0.015	0.1	0.222	0.264	0.246	0.279	0.254
Petro	0.08	350	0.015	0.1	0.300	0.214	0.296	0.256	0.269
Petro	0.08	400	0.015	0.1	0.211	0.228	0.231	0.238	0.241

CHAPTER 4

DATA ANALYSIS

Experimental Data

Visual inspection of tool wear data at the three cutting fluid conditions listed in Table 1 found that the tool wear in the two cutting fluid conditions was consistently smaller than in the dry condition. Overall, all the tool wear data in Table 1 under fluid conditions are smaller than 0.5mm flank tool wear, which is the cutoff value set by ISO for defining an effective tool life. The example pictures about tool inserts with the flank wear at dry, soybean and petroleum conditions are following.

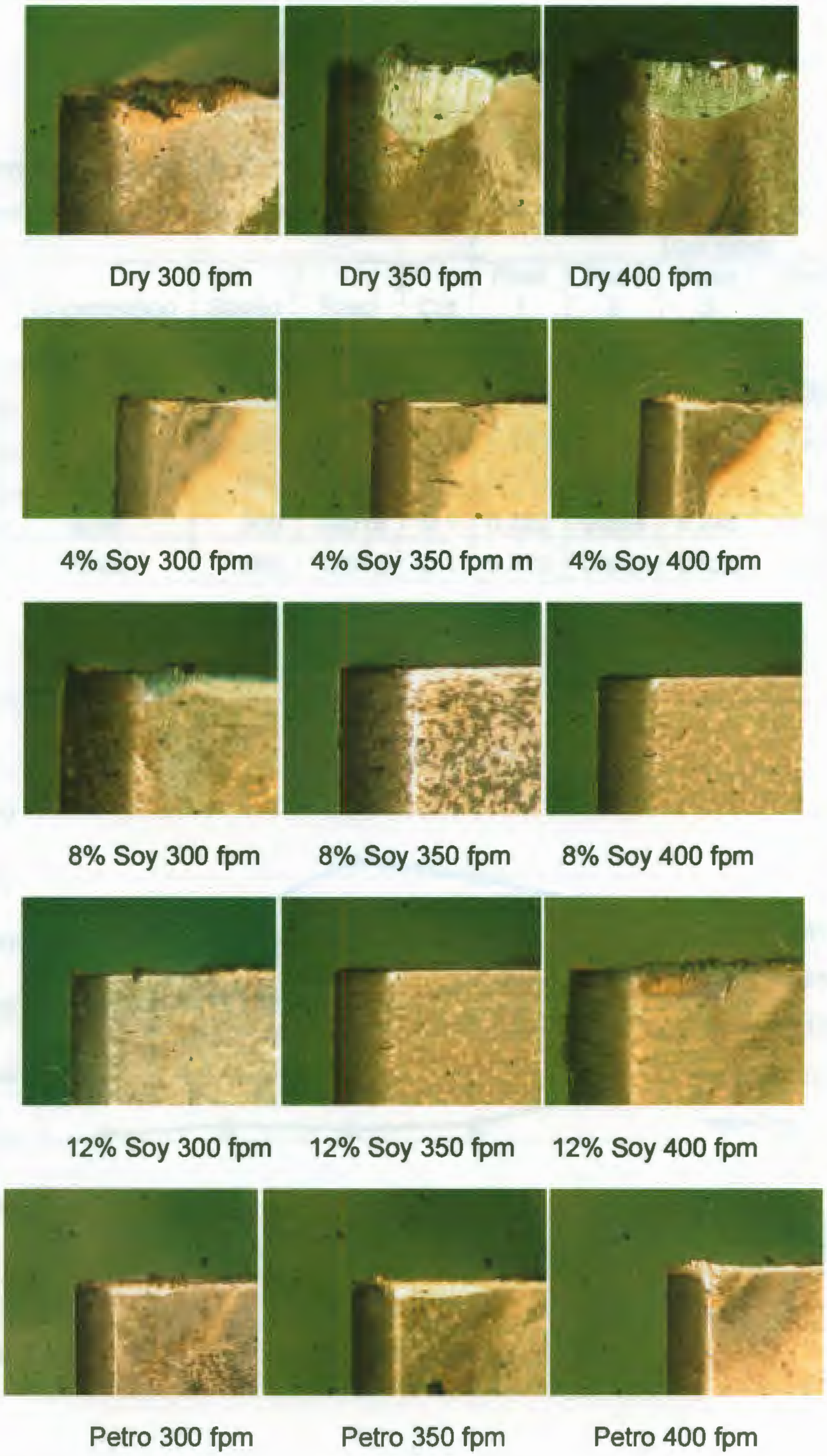

Figure 5. Tool Wear

Comparisons of Tool Wear at Different Cutting Fluid Conditions at Different Cutting Speeds

Table 2
Data for Five Conditions at 300 fpm

					Tool Wear				
Fluid	Concentration	Speed	Feed	Cut	Pass 1	Pass 2	Pass 3	Pass 4	Pass 5
comparison at 300 fpm									
Soy 4%	0.04	300	0.015	0.1	0.295	0.322	0.301	0.338	0.345
Soy 8%	0.08	300	0.015	0.1	0.281	0.265	0.271	0.214	0.255
Soy 12%	0.12	300	0.015	0.1	0.111	0.123	0.117	0.125	0.174
Petro 8%	0.08	300	0.015	0.1	0.222	0.264	0.246	0.279	0.254
Dry	None	300	0.015	0.1	0.412	0.433	0.526	0.501	0.456

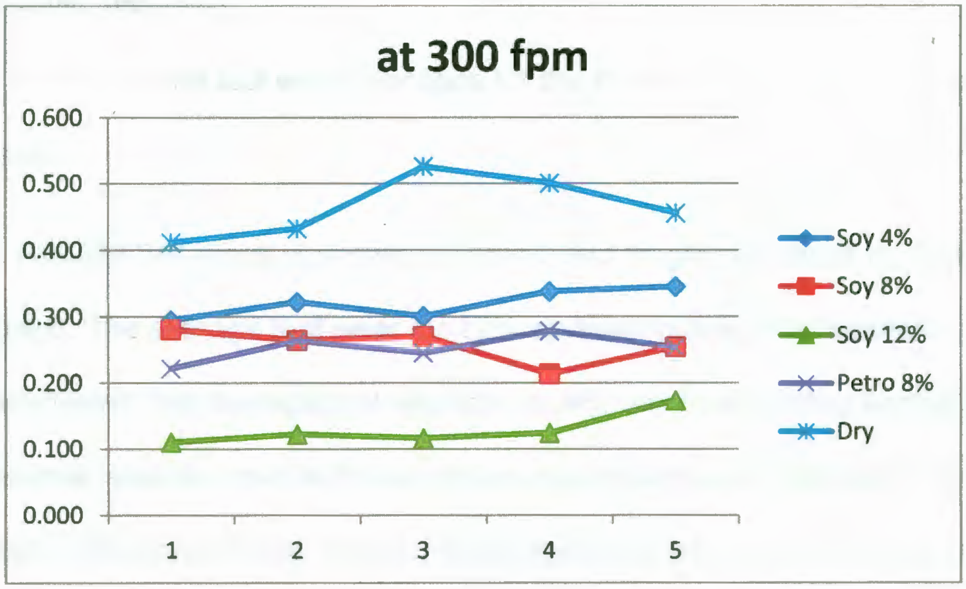

Figure 6. Graphic Result for Five Conditions at 300 fpm

Table 3
Anova for Five Conditions at 300 fpm

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.298385	4	0.074596	83.32548	3.53E-12	2.866081
Within Groups	0.017905	20	0.000895			
Total	0.31629	24				

H_0: There are no significant differences among the cutting fluid conditions (W_1=W_2=W_3 =W_4=W_5).

H_1: Not all the tool wear averages for the three soy cutting fluid conditions are equal.

The ANOVA result is shown in Table 3 and its graphic result is displayed in Figure 6. The average tool wear for 12% soybean cutting fluid condition is at the lowest level, the average tool wear for the 4% soy bean cutting fluid at the highest level, and the one for 8% soy bean oil is in between. Representing the probability, the circle for the 12% condition stands far away from the other two circles, which means the tool wear for the 12% condition was significantly different from the other two conditions. In other words, the application of cutting fluids significantly reduced tool wear. The small probability value (<0.0001) given by the F-test in the ANOVA analysis in Table 3 confirmed this observation. Therefore, the null hypothesis should be rejected.

The hypotheses test above only tells that there were significant differences among treatments in the experiment as a whole. Following the hypotheses test, further, the t-test was performed to identify which cutting fluid conditions generated the tool wear difference from one another. The least significant difference (LSD) can be computed by following formula.

$$LSD = t_{\alpha/2}\sqrt{MSE\,(\frac{1}{n_1}+\frac{1}{n_2})}$$

Where n_1 and n_2 are the number of samples collected in each cutting fluid condition, $n_1 = n_2 = 5$.

MSE is the mean square error displayed in Table 3, MSE = 0.000895.

If using Student's t, $t_{a/2}$ is the t-value corresponding to the significant level α (pre-determined as 0.05) at degree of freedom 20 $t_{a/2} = 2.086$. Using the Bonferroni adjustment, as there are 10 pair comparisons in this experiment, the significant level for the pair comparison can be adjusted to 0.005 (=0.05/10). Therefore correspondingly, $t_{a/2}$ is the t-value at probability of 0.0025 with the degree of freedom 20, $t_{a/2} = 3.445$. The LSD can be computed as follows.

$$LSD = 2.086\sqrt{0.000895 \times (\frac{1}{5}+\frac{1}{5})} = 0.0394$$

$$LSD_{adj} = 3.445\sqrt{0.000895 \times (\frac{1}{5}+\frac{1}{5})} = 0.0652$$

Table 4
Variance for Five Conditions at 300 fpm

SUMMARY				
Groups	*Count*	*Sum*	*Average*	*Variance*
Row 3 (12%)	5	0.65	0.13	0.000635
Row 4(P8%)	5	1.265	0.253	0.000452
Row 2(S8%))	5	1.286	0.2572	0.000672
Row 1(4%)	5	1.601	0.3202	0.000485
Row 5 (dry)	5	2.328	0.4656	0.002232

Based upon the calculated LSD, because the difference of at 8% P &S, there difference is 0.0042 less than LSD, then they are compatible, the surface roughness results at the dry and petroleum cutting conditions are significantly different. Similarly, the surface roughness results at the dry and soy cutting conditions are significantly different, as their mean difference 2.962 is larger than LSD. It can be seen clearly that there is no difference between the petroleum and the soy cutting conditions.

Table 5

Data for Five Conditions at 350 fpm

					Tool Wear				
Fluid	Concentration	Speed	Feed	Cut	Pass 1	Pass 2	Pass 3	Pass 4	Pass 5
comparison at 350 fpm									
Soy 4%	0.04	350	0.015	0.1	0.356	0.344	0.349	0.363	0.321
Soy 8%	0.08	350	0.015	0.1	0.219	0.226	0.299	0.354	0.234
Soy 12%	0.12	350	0.015	0.1	0.162	0.177	0.144	0.213	0.104
Petro 8%	0.08	350	0.015	0.1	0.300	0.214	0.296	0.256	0.269
Dry	None	350	0.015	0.1	0.436	0.487	0.498	0.527	0.478

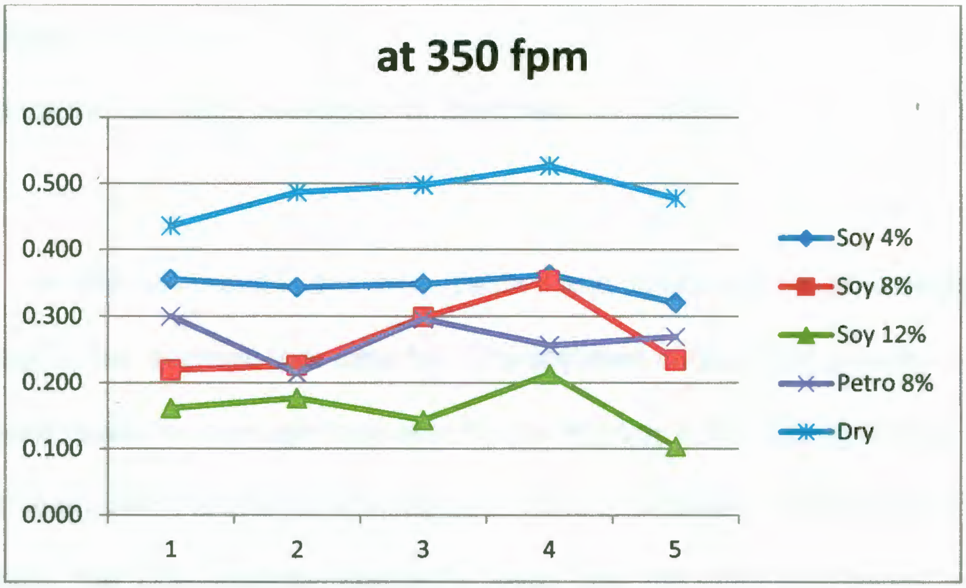

Figure 7. Graphic Result for Five Conditions at 350 fpm

Table 6
Anova *for Five Conditions at 350 fpm*

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.290895	4	0.072724	47.73639	5.9E-10	2.866081
Within Groups	0.030469	20	0.001523			
Total	0.321364	24				

H_0: There are no significant differences among the cutting fluid conditions (W_1=W_2=W_3 =W_4=W_5).

H_1: Not all the tool wear averages for the three soy cutting fluid conditions are equal.

The ANOVA result is shown in Table 6 and its graphic result is displayed in Figure 7. The average tool wear for 12% soybean cutting fluid condition is at the lowest level, the average tool wear for the 4% soy bean cutting fluid at the highest level, and the one for 8% soy bean oil is in between. Representing the probability, the 12% condition stands far away from the other two circles, which means the tool wear for the 12% condition was significantly different from the other two conditions. In other words, the application of cutting fluids significantly reduced tool wear. The small probability value (<0.0001) given by the F-test in the ANOVA analysis in Table 6 confirmed this observation. Therefore, the null hypothesis should be rejected.

The hypotheses test above only tells that there were significant differences among treatments in the experiment as a whole. Following the hypotheses test, further, the t-test was performed to identify which cutting fluid conditions generated the tool wear difference from one another. The least significant difference (LSD) can be computed by formula.

$$LSD = t_{\alpha/2}\sqrt{MSE\left(\frac{1}{n_1}+\frac{1}{n_2}\right)}$$

Where n_1 and n_2 are the number of samples collected in each cutting fluid condition, n_1 = n2 =5.

MSE is the mean square error displayed in Table 6, MSE = 0.001523.

If using Student's t, $t_{a/2}$ is the t-value corresponding to the significant level α (pre-determined as 0.05) at degree of freedom 20 $t_{a/2}$ = 2.086. Using the Bonferroni adjustment, as there are 10 pair comparisons in this experiment, the significant level for the pair comparison can be adjusted to 0.005 (=0.05/10). Therefore correspondingly, $t_{a/2}$ is the t-value at probability of 0.0025 with the degree of freedom 20, $t_{a/2}$ = 3.445. The LSD can be computed as follows.

$$LSD = 2.086\sqrt{0.001523 \times \left(\frac{1}{5}+\frac{1}{5}\right)} = 0.0515$$

$$LSD_{adj} = 3.445\sqrt{0.001523 \times \left(\frac{1}{5}+\frac{1}{5}\right)} = 0.0850$$

Table 7
Variance for Five Conditions at 350 fpm

Anova: Single Factor				
SUMMARY				
Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1 (12% Soy)	5	1.473	0.15994	0.011773
Row 2 (8%S)	5	1.448	0.2664	0.016091
Row3 (8%P)	5	1.586	0.267	0.01612
Row 4 (4%)	5	1.713	0.3466	0.014711
Row 5 (dry)	5	1.4057	0.4852	0.018549

Based upon the calculated LSD, because the difference of at 8% P &S, there difference is 0.0006 less than LSD, then the effect of soybean cutting fluid at 8% is compatible to the petroleum at 8%.

Table 8

Data for Five Conditions at 400 fpm

					Tool Wear				
Fluid	Concentration	Speed	Feed	Cut	Pass 1	Pass 2	Pass 3	Pass 4	Pass 5
comparison at 400 fpm									
Soy 4%	0.04	400	0.015	0.1	0.388	0.379	0.366	0.392	0.326
Soy 8%	0.08	400	0.015	0.1	0.274	0.203	0.226	0.221	0.231
Soy 12%	0.12	400	0.015	0.1	0.237	0.100	0.139	0.137	0.155
Petro 8%	0.08	400	0.015	0.1	0.211	0.228	0.231	0.238	0.241
Dry	None	400	0.015	0.1	0.555	0.565	0.597	0.578	0.489

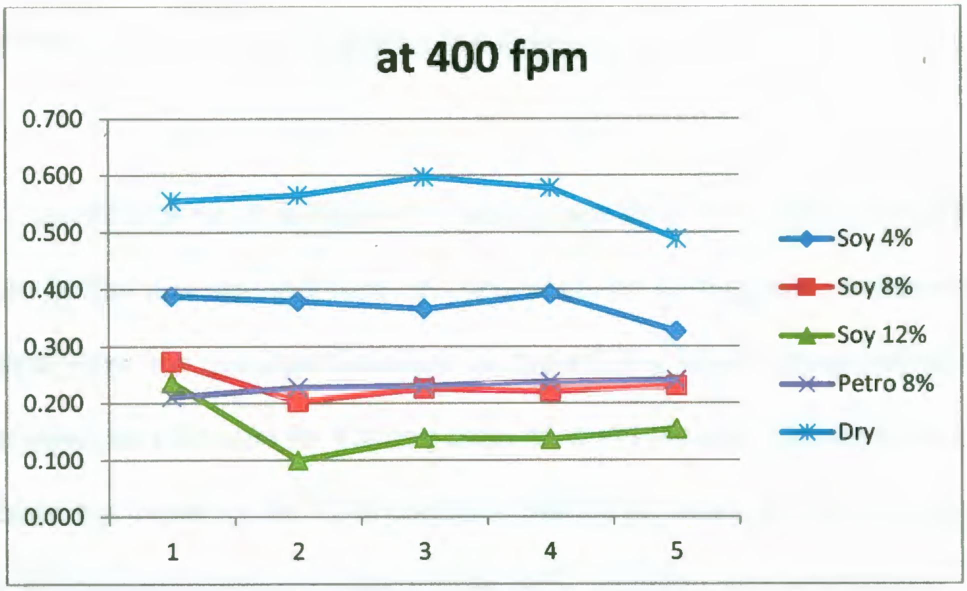

Figure 8. Graphic Result for Soy Oil and Petroleum 400 fpm

Table 9
Anova *for Five Conditions at 400 fpm*

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.508267	4	0.127067	109.5328	2.66E-13	2.866081
Within Groups	0.023202	20	0.00116			
Total	0.531469	24				

H_0: There are no significant differences among the cutting fluid conditions (W_1=W_2=W_3 =W_4=W_5).

H_1: Not all the tool wear averages for the three soy cutting fluid conditions are equal.

The ANOVA result is shown in Table 9 and its graphic result is displayed in Figure 8. The average tool wear for 12% soybean cutting fluid condition is at the lowest level, the average tool wear for the 4% soy bean cutting fluid at the highest level, and the one for 8% soy bean oil is in between. Representing the probability, the circle for the 12% condition stands far away from the other two circles, which means the tool wear for the 12% condition was significantly different from the other two conditions. In other words, the application of cutting fluids significantly reduced tool wear. The small probability value (<0.0001) given by the F-test in the ANOVA analysis in Table 9 confirmed this observation. Therefore, the null hypothesis should be rejected.

The hypotheses test above only tells that there were significant differences among treatments in the experiment as a whole. Following the hypotheses test, further, the t-test was performed to identify which cutting fluid conditions generated the tool wear difference from one another. The least significant difference (LSD) can be computed by formula.

$$LSD = t_{\alpha/2}\sqrt{MSE\ (\frac{1}{n_1}+\frac{1}{n_2})}$$

Where n_1 and n_2 are the number of samples collected in each cutting fluid condition, n_1 = n2 =5.

MSE is the mean square error displayed in Table 9, MSE = 0.00116.

If using Student's t, $t_{a/2}$ is the t-value corresponding to the significant level α (pre-determined as 0.05) at degree of freedom 20 $t_{a/2}$ = 2.086. Using the Bonferroni adjustment, as there are 10 pair comparisons in this experiment (namely as dry vs. petroleum, dry vs. soy petroleum vs. soy), the significant level for the pair comparison can be adjusted to 0.005 (=0.05/10). Therefore correspondingly, $t_{a/2}$ is the t-value at probability of 0.0025 with the degree of freedom 20, $t_{a/2}$ = 3.445. The LSD can be computed as follows.

$$LSD = 2.086\sqrt{0.00116 \times (\frac{1}{5}+\frac{1}{5})} = 0.0449$$

$$LSD_{adj} = 3.445\sqrt{0.00116 \times (\frac{1}{5}+\frac{1}{5})} = 0.0742$$

Table 10
Variance for Five Conditions at 400 fpm

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 3 (12%)	5	0.768	0.1536	0.00258
Row 4 (8%P)	5	1.149	0.2298	0.000138
Row 2 (8%S)	5	1.155	0.231	0.00069
Row 1 (4%)	5	1.851	0.3702	0.00071
Row 5 (Dry)	5	2.784	0.5568	0.001683

Regression Model of Tool Wear and Soy Concentrations

Response TW Whole Model

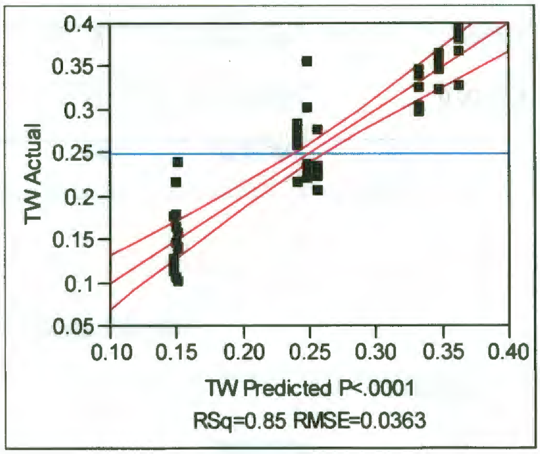

Figure 9. Actual by Predicted Plot Whole Model

Table 11
Summary of Fit Whole Model

RSquare	0.846082
RSquare Adj	0.83482
Root Mean Square Error	0.036251
Mean of Response	0.248356
Observations (or Sum Wgts)	45

Table 12
Analysis of Variance Whole Model

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	0.29617980	0.098727	75.1253
Error	41	0.05388051	0.001314	**Prob > F**
C. Total	44	0.35006		<.0001

Table 13
Parameter Estimates Whole Model

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.3908556	0.048486	8.06	<.0001
Speed	0.000158	0.000132	1.19	0.2395
Soy	-2.4725	0.165464	-14.94	<.0001
(Speed-350)*(Soy-0.08)	-0.0033	0.004053	-0.81	0.4202

Whole Model

$$Tw = 0.3908 + 0.000158Speed - 2.4725Soy - 0.0033(Speed - 350)(Soy - 0.08)$$

Model is useful to explain the variations in tool wear at different concentrations because the P-value for the model is very small (<0.0001) in Table 11. The summary of the model can be found in Table 12 In the parameter estimate table 13, since the probability values for speed and the interaction items are larger than 0.05, these two items are not significant. The intercept and soy concentration are the two significant factors. Only including the soy concentration and the intercept, a reduced linear regression model is established as follows:

$$Tw = 0.4461556 - 2.4726Soy$$

As can be seen in Table 14, the RSquare value (0.838245) of the reduced model is very close to the one of the full regression model, which is 0.8406. But the reduced regression model is a much simpler equation.

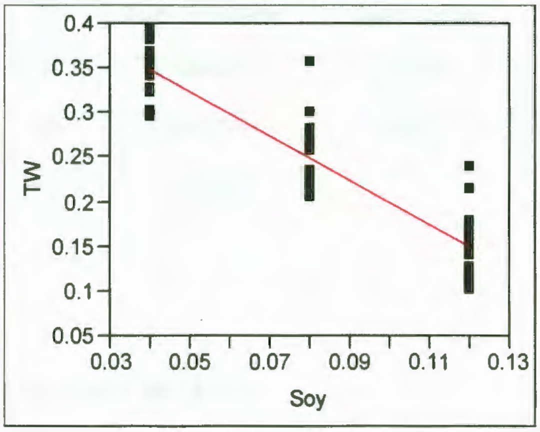

Figure 10. Response TW Reduced Model

Table 14
Summary of Fit Reduced Model

RSquare	0.838245
RSquare Adj	0.834483
Root Mean Square Error	0.036288
Mean of Response	0.248356
Observations (or Sum Wgts)	45

Table 15
Analysis of Variance Reduced Model

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.29343630	0.293436	222.8341
Error	43	0.05662401	0.001317	**Prob > F**
C. Total	44	0.35006031		<.0001

Table 16
Parameter Estimates Reduced Model

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.4461556	0.014312	31.17	<.0001
Soy	-2.4725	0.165632	-14.93	<.0001

ANOVA Analyses on Tool Wear

Table 17

Analysis of Variance for Soy Oil

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Soy	2	0.29366351	0.146832	109.3490	<.0001
Error	42	0.05639680	0.001343		
C. Total	44	0.35006031			

Table 18

Means for Oneway Anova for Soy Oil

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
0.04	15	0.345667	0.00946	0.32657	0.36476
0.08	15	0.251533	0.00946	0.23244	0.27063
0.12	15	0.147867	0.00946	0.12877	0.16696

Table 19

t for Soy Oil

T	Alpha
2.01808	0.05

Table 20
Means Comparison for Soy Oil

Abs(Dif)-LSD	**0.04**	**0.08**	**0.12**
0.04	-0.02700	0.06713	0.17080
0.08	0.06713	-0.02700	0.07666
0.12	0.17080	0.07666	-0.02700

Table 21
Means for Soy Oil

Level				Mean
0.04	A			0.34566667
0.08		B		0.25153333
0.12			C	0.14786667

CHAPTER 5

CONCLUSION

The experiments show that the soy oil at 8% performs just as well as the petroleum fluid when mixed at the manufacturer's suggested ratio which is 8. The tool wear shows the normal amount of wear when either solution is used.

The soy oil at 12% is significantly a better performer but the cost would have to be taken into consideration when using. The cost of soy oil is higher compared to that of the petroleum fluid (Bos, 2010).

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