Effect of Maize-Starch Based Cutting Fluids and Machining Parameters on Temperature Generated in Turning of AISI 304 Stainless Steel

M. O. Abiodun, Olutosin O. Ilori and K. M. Adeleke

Abstract*—This study prepared, characterized maize-starch based cutting fluids and examined its effect combined with some machining parameters on heat generated during turning of AISI 304 stainless steel with a view to determine the suitability of the maize-starch for use as cutting fluid. The maize-starch cutting fluids were prepared by mixing 10% of soluble and coconut oils with maize-starch paste. Other cutting fluids used were water mixed with soluble oil and straight coconut oil. The viscosity, specific gravity of each cutting fluid and temperature at the cutting zone were determined. The results show that the kinematic viscosities for soluble oil, coconut oil, maize-starch mixed with soluble and coconut oils were 38.0, 37.98, 36.04 and 35.44 cSt, respectively. Also, the specific gravities for the cutting fluids were 0.99, 0.92, 1.06 and 1.06, respectively. Increases in depth of cut, cutting speed and feed rate increases the temperature produced at the tool-workpiece interface while increases in cutting fluid flow rate reduces the temperature using the four cutting fluids. Likewise, the maize-starch mixed with soluble oil demonstrated the best fluid since it gave the lowest temperatures at all levels of depth of cuts, fluids flow rates, cutting speeds and feed rates when compared with the other cutting fluids used. Therefore, if coconut oil could be used as a coolant in machining process, certainly, this study suggest that maize-starch mixed with soluble oil is suitable and superior to the other fluids with respect to lubricity and cooling effect when used in turning AISI 304 stainless steel.

***Keywords*— Maize-Starch, Cutting Fluids, Machining Parameters, Temperature, Turning and Stainless Steel**

I. INTRODUCTION

Machining of AISI 304 stainless steel is more difficult compared to other low-alloy steels due to some characteristics such as high strength, low thermal conductivity, high ductility, high work hardening tendency, poor surface finish, high force and high tool wear [1]. A significant part of the energy is converted into heat energy through the friction generated between the tool and the workpiece which cause the plastic deformation of the workpiece material in the machining zone during machining operation [2], [3]. The temperature of the tool and workpiece interface increase at a fast rate due to rapid heat generated at the interface and invariably leads to softening of the workpiece which may involve structural transformation of the workpiece and tool material [2], [4]. The heat generated in machining operation is crucial to the quality of product. References [2], [5] stated that effective control of heat generated in the cutting zone during metal removal is important in ensuring good workpiece surface quality. The prediction of cutting temperature is the most difficult and hot topics in the study of metal cutting process. There are several experimental methods such as embedded thermocouple and infrared technique to measure cutting temperatures at tool-workpiece-chip interface [6]. Also, it has been established that the use of cutting fluid provides longer tool lives compared to dry cutting especially in continuous machining process such as turning; attempts have been made to increase its performance by directing its flow to contact regions and using high-pressure fluid [7].

Cutting fluids are used as lubricant in machining processes to increase tool life, enhance machining efficiency and provide good surface quality by means of cooling and lubricating at the tool-workpiece interface [8]. The cutting fluids produce three positive effects in the process; heat elimination, lubrication at the tool-workpiece interface and chip removal [9]. One of the main reasons of using cutting fluid in machining processes is to reduce heat generated at the cutting zone in order to increase tool life. But its advantages have been called into question in recent times due to the harmful effects on product cost, environment and human health. The present trend towards new types of cutting fluids based on vegetable oils and esters in machining operations is clearly justified by their higher biodegradability and lower environmental impact. Reference [10] reviewed tribological properties and machining performance of vegetable oil based metal working fluids. They revealed that vegetable oils increased machining performance, improved product quality by reducing cutting force/thrust force, increasing surface quality, reduced tool wear, good heat dissipating ability and lower environmental impact can be obtained with vegetable oils-based cutting fluids. Reference [2] reported that it is a general local practice in the western part of Nigeria to apply maize-starch paste to a part of the human body which hot

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liquid spills by accident in order to reduce the temperature and prevent the development of the wounds that could have otherwise developed on the affected part of the body.

Preliminary study carried out indicated that maize-starch paste has relatively high thermal conductivity and specific heat capacity. This is a pointer to the fact that it could have high potentials for reducing temperature produced at the cutting zone, minimizing rate of tool wear and increasing effort of making use of vegetable based fluid as an alternative cutting fluid in machining processes to improve the quality of the workpiece by frequently removing chips from the tool and cutting zone. It may also alleviate problems faced by workers such as skin cancer and inhalation of toxic mist in the work environment.

Therefore, this study formulated, characterized maize-starch based cutting fluids and examined its effect combined with some machining parameters like depth of cut, feed rate, speed and fluid flow rate on temperature generated in turning of AISI 304 stainless steel using P35 coated carbide tool.

II. EXPERIMENTAL PROCEDURE

A) Materials

The materials used in carrying out the experiment include dry maize kernels, AISI 304 stainless steel, P35 coated carbide cutting tool, soluble oil, coconut oil. The dry maize kernels were sourced from a local market for the production of the maize starch. Also, the equipment used include center lathe machine, magnetic stirrer, digital multimeter, type-K thermocouple, electronic balance, water bath, Canon-Fensky viscometers, pour and cloud point tester.

B) Production of the Maize-starch

The dry yellow open-pollinated maize kernels were soaked in warm water (60^{o}C) in a room (at room temperature) for two days. The temperature of the room and the soaked maize kernels were monitored at interval of two hours to know the condition at which the maize kernels was soaked and before grinding. After two days, the water used to soak the maize kernel was removed and the soaked maize kernel was washed with cleaned water before it was taken for grinding. The ground maize kernel was sieved to separate the chaff from the maize starch. The separated maize-starch was allowed to settle for a day before it was ready for use.

C) Determination of Moisture Content of the Maize-starch

The moisture content of the fresh maize-starch was determined by oven drying method. A measure of 100g of maize-starch was weighed into a dried metallic container of known weight. The container was placed in the oven and heated at 110^{o}C for two hours. They were placed inside a desiccator to cool for thirty minutes after removal from the oven. The container and maize-starch was weighed again in order to know the weight loss during heating. The moisture content of the maize-starch was determined using Equation (1).

$$\text{Moisture content } (\%) \text{w.b.} = \frac{W_3 - W_1}{W_2 - W_1} \times 100 \quad \ldots \ (1)$$

where W_1 in g is the initial weight of petri dish, W_2 in g is the weight of petri dish and sample and W_3 in g is the final weight of petri dish and sample after drying.

D) Production of the Cutting Fluids

The maize-starch was mixed with water in equal proportion by volume to make up a paste. One cutting fluid was formulated by mixing 10% soluble oil with the maize-starch paste. The second fluid was formulated by mixing 10% coconut oil with the maize-starch paste. These formulations were mixed to obtain even solution using the magnetic stirrer for 30 minutes. The heater of the stirrer was put off in the process of mixing because at temperature exceeding 80^{o}C the solution begins to coagulate. Also, the soluble oil was added to water in the same proportion to form a third cutting fluid. The fourth fluid is straight coconut oil.

E) Characterizations of the Formulated Cutting Fluids

The following tests were performed on the four cutting fluids (soluble oil, coconut oil, maize-starch mixed with soluble oil and maize-starch mixed with coconut oil).

i. Specific gravity

This was done with the aid of the specific gravity bottle. The four fluids were poured into a 1000ml measuring cylinder one after the other. Graduated glass hydrometers were dropped inside the fluid such that substantial part of the calibrated side can buoyed. Measurement was taken when stability was attained. The specific gravity was determined at 28^{o}C and converted to specific gravity at 15^{o}C using Equation (2);

$$\text{S.g.}_{@15^{\mathbf{o}}\text{C}} = [(T - 15^o\text{C}) * 0.00061] + \text{observed S.g.} \quad \ldots \ (2)$$

where T is the temperature at which the specific gravity was determined. This process was replicated twice and average result was taken.

ii. Viscosity

The viscosity test was performed for the four fluids. The water bath was maintained at 40^{o}C. The fluids were poured into the viscometers having the constant C = 0.1 respectively. They were placed in the water bath for 30 minutes to attain uniform temperature of 40^{o}C. The fluids were pumped into the capillary/orifice side such that its flow from the upper mark to the next mark was timed (in seconds). The process was repeated twice to eliminate experimental error and average result was taken.

iii. Cloud and pour point

The cloud and pour points were determined by placing the fluids inside a special test tube which were placed inside cold bath. The cooling of the fluids continued until the fluids became solidified. The temperature points at which the first crystallization of solid was formed in the form of haze or cloud were taken as the cloud points. Likewise, the temperature points at which fluids became plastic solids and deformation seizes were taken as the pour points.

F) Experimental design

A center lathe was used to carry out the machining experiments. The workpiece was fixed and held by the jaw chuck, and the P35 coated carbide cutting tool insert was clamped on a rigid tool holder of the machine at approach angle of 90^{o}. The temperature generated at the cutting zone was recorded at the end of each experimental run with the help of the thermocouple inserted between the tool insert and its holder. In this study, four machining parameters were considered for the experimentation for each fluid formulation namely; depth of cut, cutting speed, feed rate and fluid flow rate. Three levels were assigned to each of the four parameters (Table 1). This experimentation was based on Taguchi's design of experiment and orthogonal array [11]. Based on this experimental design approach, only 9 experimental runs were made. Therefore, for the four fluid formulations, a total of 36 experimental runs were made and replicated twice.

Table I: Machining Parameters with their levels

Levels	Machining Parameters			
	Depth of Cut (mm)	Cutting Fluid Flow Rate (ml/min)	Cutting Speed (m/min)	Feed Rate (mm/rev)
Low	1.0	200	34	0.08
Medium	2.0	600	68	0.16
High	3.0	1000	97	0.24

III. RESULTS AND DISCUSSION

A) Characterization of the Formulated Cutting Fluids

Table II gives the kinematic viscosity at temperature 40^{o}C, specific gravity, pour point, and cloud point of the four cutting fluids.

i. Viscosity of the cutting fluids

Coconut oil has viscosity of 37.975 cSt at a temperature of 40^{o}C. Soluble oil has a viscosity of 38.0 cSt; while the blends of maize-starch with soluble oil and maize-starch with coconut oil have viscosities of 36.042 cSt and 35.436 cSt respectively at 40^{o}C (Table 2). All the fluids were adjudged suitable for lubrication given their viscosities at 40^{o}C, which correspond to some guidelines given by [12], that fluids for lubrication should have viscosities in the range of 35 to 40 cSt at 40^{o}C.

ii. Specific gravity of the cutting fluids

The specific gravity at 15^{o}C for soluble oil is 0.991, coconut oil is 0.915 while that of the blends of maize-starch with soluble oil and maize-starch with coconut oil are 1.058 and 1.060 respectively (Table 2). The values of specific gravity obtained for the blends of maize-starch with soluble oil and maize-starch with coconut oil shows that the blends are heavier than water and will not float when spilled in water.

iii. Pour point and cloud point of the cutting fluids

The pour point is the lowest temperature at which the oil becomes solidified. Pour point is the most important low temperature property of any oil used as a lubricant. From the results in Table 2, it can be seen that soluble oil has the lowest pour point, -9^{o}C, and coconut oil has the highest pour point, 5^{o}C; maize-starch mixed with soluble oil has a pour point of -1^{o}C while maize-starch mixed with coconut oil has a pour point of 2^{o}C. It can also be seen from the Table that the cloud points of soluble oil, coconut oil, maize-starch mixed with soluble oil and maize-starch mixed with coconut oil are -15, 2, -5 and -3^{o}C respectively. In order to have a good low temperature property as a lubricant, a fluid should have a low pour point and a cloud point preferably below 0^{o}C [13]; this shows that coconut oil and maize-starch mixed with coconut oil have poor low temperature property as lubricants. The low temperature property can however be further enhanced by the application of pour point depressant additives.

Table II: Characterization of the cutting fluids

Test	Soluble oil	Coconut oil	Maize-starch mixed with soluble oil	Maize-starch mixed with coconut oil
Viscosity @ 40^{o}C (cSt)	38.0	37.975	36.042	35.436
Pour point (^{o}C)	-9	5	-1	2
Cloud point (^{o}C)	-15	2	-5	-3
Specific gravity @ 15^{o}C	0.991	0.915	1.058	1.060

B) Performance of the Cutting Fluids with respect to Heat Generated

The temperature at cutting zone between the workpiece and cutting tool interface was considered to understand the performance of the cutting fluids as a metal working fluid when machining AISI 304 stainless steel.

i. Effect of depth of cut on temperature generated

Fig. 1 shows the plot between the depths of cut and the temperature obtained during the turning process using the different cutting fluids at a constant cutting speed of 34 m/min. It was observed generally that the temperature increases as the depth of cut increases. The mix of maize-starch with soluble oil gives a better reduction in temperature at different levels of depth of cut compared to the other three cutting fluids used. It was observed from the Figure as the depth of cut increases, coconut oil began with temperature of 47.5^{o}C at depth of cut of 1.0 mm which went up to 92.5^{o}C at depth of cut of 3.0 mm. Reference [2] reported the rise in this temperature may be due to the fact that as the depth of cut increases, the tool cut more material from the surface of the workpiece and the energy required to form the chips increases thus increasing the temperature at the cutting zone. Likewise, using maize-starch mixed with coconut oil as cutting fluid, temperature generated was 40^{o}C at 1.0 mm depth of cut. This got higher to 45^{o}C at 3.0 mm depth of cut. Also, it was observed that as the depth of cut increases, soluble oil started with temperature of 37.5^{o}C at depth of cut of 1.0 mm which rose to 45.5^{o}C at depth of cut of 3.0 mm.

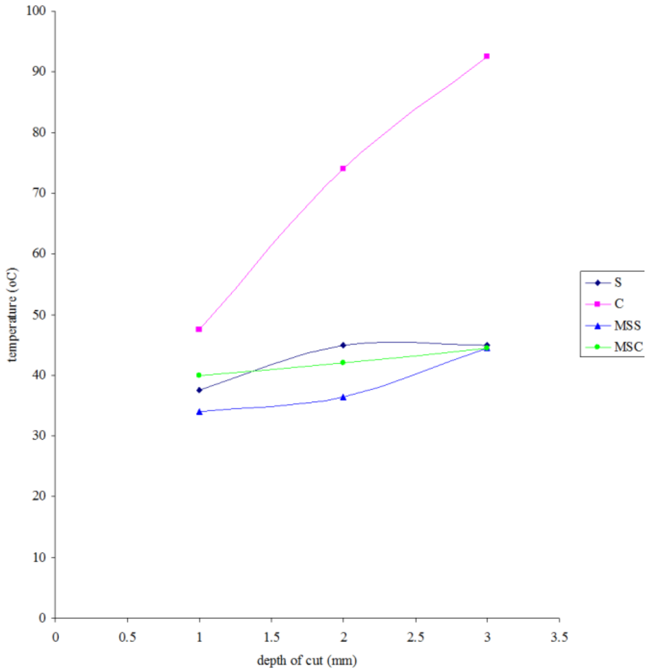

Fig. 1: Temperature against depth of cut at constant cutting speed of 34 m/min

Note: C - Coconut oil; S – Soluble oil mixed with water; MSS – Maize starch mixed with soluble oil; MSC – Maize starch mixed with coconut oil.

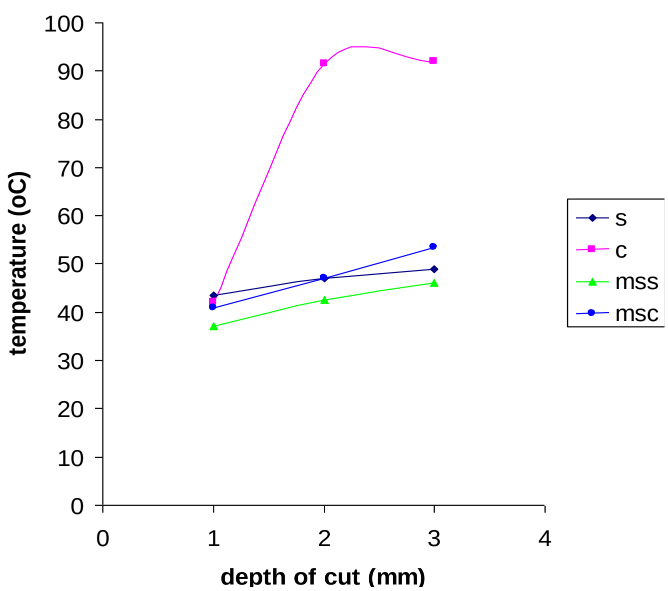

Fig. 2: Temperature against depth of cut at constant cutting speed of 68 m/min

Correspondingly, using maize-starch mixed with soluble oil, the temperature at 1.0 mm depth of cut was 34°C and increased to 44°C at 3.0 mm depth of cut. Similar results were observed at different levels of depth of cut at constant speeds of 68 and 97 m/min among the four cutting fluids (Fig. 2 and Fig. 3). Therefore, coconut oil showed the highest rise in the temperatures at all the levels of depth of cut at constant speeds of 34 m/min, 68 and 97 m/min among the four cutting fluids. This could be due to the fact that coconut oil has a poor cooling property as suggested by [14]. If coconut oil could be used as a coolant in the machining process, certainly, these results suggest that maize-starch based fluids have better potentials for use as cutting fluids; potentials that appear even better than we have for the more conventional mixture of soluble oil and water.

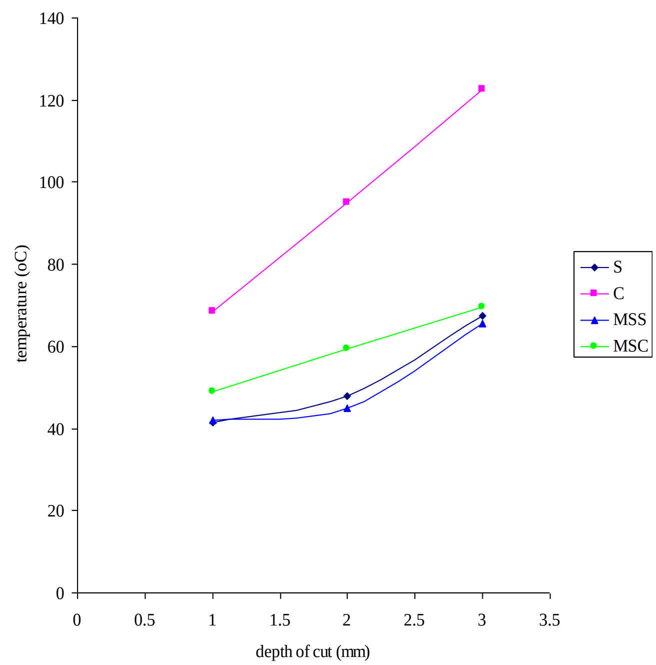

Fig. 3: Temperature against depth of cut at constant cutting speed of 97 m/min

ii. Effect of cutting fluid flow rate on temperature generated

It was found that at a constant depth of cut of 3.0 mm, the temperature at the tool-workpiece interface decreases with increase in the cutting fluids flow rate (Fig. 4). As the fluids flow rate increases from 200 ml/min to 1000 ml/min, the temperature generated using all the cutting fluids decreases continuously. For instance, when machining with soluble oil, the temperature decreases from 67.5°C to 45°C; it decreases from 122.5°C to 92.5°C for coconut oil; temperature decreases from 69.5°C to 44.5°C for maize-starch mixed with coconut oil; and for maize-starch mixed with soluble oil, the decrease was from 65.5°C to 44.5°C. The decrease in temperature with increasing flow rate was anticipated because the rate of heat convection at the cutting zone intensified with high flow rate and consequently less heat gathered at the tool-workpiece interface [2]. Therefore, the best cutting fluid with the least temperature at all levels of fluids flow rate is the maize-starch mixed with soluble oil compared with the other three cutting fluids.

iii. Effect of cutting speed on temperature generated

Fig. 5 illustrates that as the cutting speed increases, the temperature generated at the tool-workpiece interface increases at a constant depth of cut of 3.0 mm using different cutting fluids. The increase in the temperature may possibly be due to the increase in energy input during machining at increased speed; also, the temperature at the cutting zone may increase with increase in contact area between chips and the

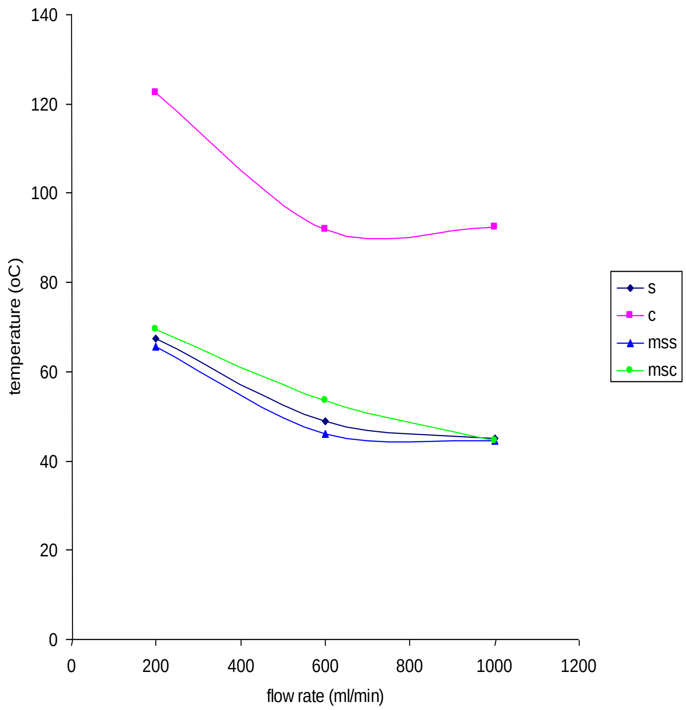

Fig. 4: Temperature against flow rate at constant cutting speed of 34 m/min

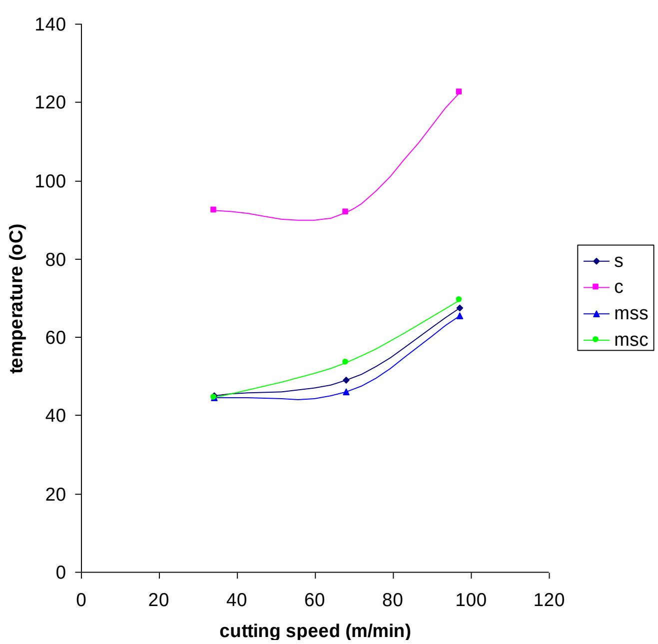

Fig. 5: Temperature against cutting speed at constant depth of cut of 3.0 mm

cutting edge as reported by [2]. As the cutting speed increases from 34 m/min to 97 m/min, it was observed that the coconut oil started off with the highest temperature of 92.5°C at constant cutting speed of 34 m/min which rose to 122.5°C at cutting speed of 97 m/min. Also as the cutting speed increases from 34 m/min to 97 m/min, temperature increases from 44.5°C to 65.5°C for maize-starch mixed with soluble oil. Soluble oil mixed with water and maize-starch mixed with coconut oil also exhibited the same trend of increase in temperature from 45°C and 44.5°C to 67.5°C and 69.5°C respectively when the cutting speed increases. The maize starch mixed with soluble oil displayed the best fluid since it gave the lowest temperatures at all levels of the cutting speed when compared with the other three cutting fluids used.

iv. Effect of feed rate on temperature generated

Fig. 6 shows the increase in temperature as the feed rate increases using the four different cutting fluids at a constant cutting speed of 34 m/min during the turning process. The increase in the temperature may be due to the fact that at low values of the feed rate, the material was subjected to lower strain rate. Maize starch mixed with soluble oil began with a temperature of 34°C at a feed rate of 0.08 mm/rev and increased to 44.5°C at 0.24 mm/rev feed rate. On the other hand, coconut oil started off with the highest temperature of 47.5°C at a feed rate of 0.08 mm/rev which rose to 92.5°C at a feed rate of 0.24 mm/rev. Soluble oil mixed with water and maize starch mixed with coconut oil also showed the same trend of temperature increase with increasing feed rate, starting off from 37.5°C and 40°C and rising to 45°C and 44.5°C respectively when the feed rate was increased from 0.08 mm/rev to 0.24 mm/rev. Maize starch mixed with soluble oil demonstrated to be the best cutting fluid as it gave the lowest temperatures at all levels of feed rates when likened with the other three cutting fluids used.

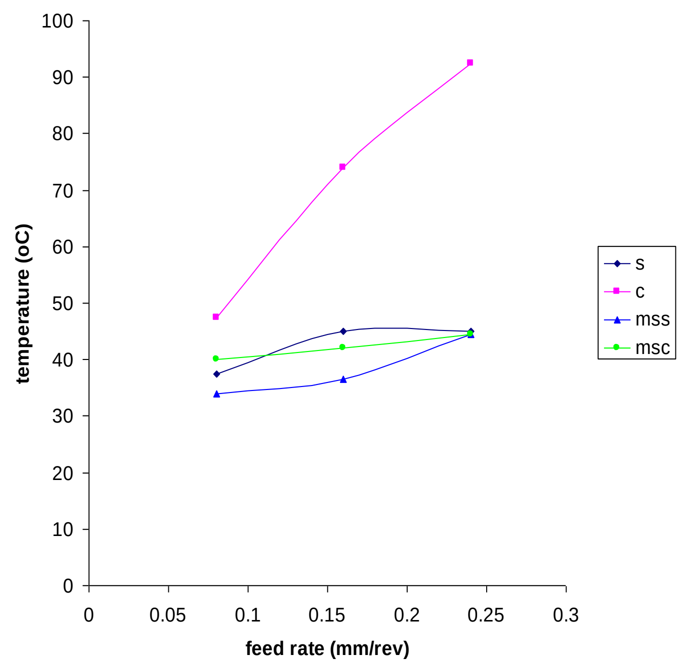

Fig. 6: Temperature against feed rate at constant cutting speed of 34m/min

IV. CONCLUSION

The study formulated, characterized maize-starch based cutting fluids (maize-starch mixed with soluble oil and maize-starch mixed with coconut oil) and examined its effect combined with depth of cut, cutting fluid flow rate, cutting speed and feed rate on temperature generated in turning of AISI 304 stainless steel using P35 coated carbide tool.

Increase in depth of cut, cutting speed and feed rate increase the temperature produced at the tool-workpiece interface while increase cutting fluid flow rate reduces the temperature generated using the four cutting fluids. Also, the maize-starch mixed with soluble oil demonstrated the best fluid since it gave the lowest temperatures at all levels of the depth of cuts, fluids flow rates, cutting speeds and feed rates when compared with the other three cutting fluids used. Therefore, if coconut oil could be used as a coolant in the machining process, certainly, the results of this study suggest that maize-starch mixed with soluble oil is superior to the other fluids with respect to lubricity and cooling effect when used in turning AISI 304 stainless steel.

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