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Research Article

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Optimization of Coolant Composition on Tool Wear during Turning Operation of Mild Steel

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Abstract Analysis of coolant usage during turning operation of mild steel was carried out to determine the coolant ratio required to improve productivity at a spindle speed of 1000 rpm and a feed rate of 0.5 rev/min. Different coolant ratios of 1:100, 1:50, 1:30, 1:25, 1:20, 1:15, 1:10, were experimented upon and it was found from analysis using surface response and regression analysis that 1:30 gave the optimum coolant ratio using the HSS cutting tool of specification (14x14x200) on mild steel work piece with respect to the conventional coolant ratio of 1:20 frequently used by machinists. It was observed from the experiment that coolant ratios of 1:30, 1:25, 1:20, 1:15 and 1:10 have a constant wear of 0.01g at a depth of cut of 0.6mm while from the analysis; it was found that optimum depth of cut was at 0.2mm to 0.4mm using coolant ratios of 1:30 to 1:10. Also, at depth of cut of 0.6mm to 0.8mm in coolant ratios of 1:100 to 1:50, the wear was more rapid and was observed to be stable at coolant ratios of 1:30 to 1:10; hence, it was seen that depth of cut and coolant ratio had a significant effect on tool wear.

Keywords Coolant ratio, Cutting tool, Lubrication, Machining, Milling, Turning

1. Introduction

Turning and milling operations are widely used in workshop practice for applications carried out in conventional and the computer numeric control machine tools, machining centres and related manufacturing systems [1]. Turning involves the use of a lathe and is used primarily to produce conical and cylindrical parts while milling involves the use of the milling machines in producing other shapes. However, with the use of attachments, flat faces, curved surfaces, grinding and boring can be carried out with the lathe machine [2]. Hence, increase in tool life helps to improve surface accuracy, reduce main cutting and feed force, and also ensure proper use of coolant to reduce machining zone temperatures (chip-tool interface temperature) in turning and milling operations. The cutting performance of Minimum Quantity Lubrication (MQL) machining is better than that of dry machining because MQL provides the benefits mainly by reducing the cutting temperature. This improves the chip-tool interaction and maintains sharpness of the cutting edges [3]. This makes coolant usage during turning of mild steel an important area of research.

Cooling and lubrication are important factors in reducing the severity of surface contact during machining operation. In metal cutting operations, there is always temperature increase between the work piece and the cutting tool interface. This is as a result of the plastic deformation developed at the primary shear plane and friction at the interface. This also affects the tool geometry as well as its thermo-physical property such as thermal conductivity, thermal diffusivity and coefficient of heat transfer due to poor lubrication of coolant.

The significance of cutting fluids in machining is widely recognized as it determines the final surface finish of any project; hence cooling lubricants are often regarded as great supporting media necessary in machining operation. With the help of compressed air, oil mist (cutting fluid) could penetrate the cutting zone and provide cooling and lubrication to the cutting tool [4]. Cutting fluid selection and supply system is based on the assumption that, “the greater the amount of lubricant used, the better the support for the cutting process”. Consequently, the contact zone between the work piece and the tool is often flooded by the cutting fluid in order to reduce the thermo-physical effect during machining. During metal cutting, the heat generated is significant enough to cause local ductility of the work piece material as well as of the cutting edge. Although softening and local ductility are required for machining hard materials, the heat generated can shorten the tool life and performance. Therefore, the control of cutting temperature is required to achieve the desired tool performance.

The temperature distribution depends on the heat conductivity and specific heat capacity of the tool and the work piece and finally the amount of heat loss based on radiation and convection [5]. The maximum temperature occurs in the contact zone between the chip and the tool. The heat generated in those zones is distributed among the tool, the work piece, the chip and after that to the environment. Heat generated at the shearing plane can make the cutting action easy, but it can flow into the cutting edge and that will negatively affect the tool life by shortening it.

The cutting temperature is a key factor which directly affects tool wear, work piece surface integrity and machining precision according to the relative motion between the tool and work piece [6]. The amount of heat generated varies according to the type of material being machined. The cutting parameters especially cutting speed, feed rate and depth of cut influence the chip-tool interface temperature. Temperature in the cutting zone depends on contact length between tool and chip, cutting forces and friction between tool and work piece material. A considerable amount of heat generated during machining is transferred into the cutting tool and work piece. The remaining heat is removed with the chips; the highest temperature is generated in the flow zone [7]. Therefore, contact length between the tool and the chip affects cutting conditions and performance of the tool and tool life.

Cutting lubricants may consist of pure oil, a mixture of two or more oils or a mixture of oil and water. Oils are generally divided into two groups: the fixed oils and the mineral oils [8]. The fixed oils have greater “oiliness” than the mineral oils, but they are not so stable and tend to become gummy and decompose when heated. In this group are animal and vegetable oils. On the other hand, the mineral oil group is obtained from crude petroleum mined from the oil fields. The most common type of lubricant used for cutting is soluble oil, which when mixed with water, forms a white solution known as “suds” or “slurry”. This has better cooling properties than oil, but does not lubricate as much. The oil part of it is generally a mineral oil mixed with a soap solution.

Several researches have been done on coolants and their effects on cutting tools in different machining processes. However not much has been said on coolant usage during turning operation of mild steel. This paper is therefore aimed at investigating coolant usage during turning operation of mild steel. To achieve this aim, the following objectives have to be met: determining the weight loss during machining, analysing the effect of depth of cut during operation for a given particular coolant ratio, determining the optimum coolant ratio for the experiment and analysing the results using statistical tool.

2. Materials and Methods

Mild steel sheets of composition (wt %) Mn (0.6), P(0.36), C(0.15) and Si(0.03) were used for the study. A work piece of standard dimensions 150mm × 40mm was mechanically cut out from the sheet for the machining operation. A High Speed Steel (HSS) cutting tool with dimension 14mm × 14mm × 200 mm, side cutting edge angle 15^o and nose radius 0.8mm was the cutting tool utilized for the operation. The Sonex premium soluble cutting oil was used in the operation and its characteristics is as stated in table I.

Table I: Characteristic value of the soluble oil

Parameter	**Value**
Sp. gravity @ 15°C	$0.933 Kg/m^3$
Viscosity @ 40°C	55 N·s m^{-2}
Viscosity @ 100°C	7.8 N·s m^{-2}
Flash point °C	130 °C
Pour point °C	-9 °C
Emulsion test	Stable milky
Corrosion	Pass

The experiment was carried out on a precision CNC lathe (CDK6150D) and the direction specification of the spindle speed of the machine is stated in table II.

Table II: Direction specification of spindle speed

Direction specification	Spindle speed (rpm)
A	177-2000
B	60-670
C	20-225

An elevated spindle speed of 1000rpm, feedrate of 0.5rev/mm and HSS cutting tool were used on Mild steel material. The Camry digital scale was used to weigh the initial mass of the tool before and after machining in order to determine the weight loss of the cutting tool.

A dial indicator having a 25.40mm range and a calibration increment of 0.0254mm was utilized for the operation.

Water was mixed with soluble oil in a ratio 1:100 for the first operation and then stirred properly before pouring into the lathe tank. The cutting operation for the experiment was performed using a written program, with a feed rate of 0.5 rev/mm, coolant ratio of 1:100 and different depth of cut ranging from 0.2-1.0mm. The initial and final weight of cutting tool was measured before and after each experiment respectively for each depth of cut. There was always regrinding of cutting tool whenever tool wear was noticed, before using it for the next operation.

The entire process was repeated for the following coolant ratios; 1:50, 1:30, 1:25, 1:20, 1: 15, 1:10 and weight losses were recorded.

3. Results and Discussion

Table III shows weight losses for various depths of cut (0.2 - 1.0mm) and consequently the different coolant ratios (1:100, 1:50, 1:30, 1:25, 1:20, 1: 15, 1:10).

Table III: Weight loss for all the coolant ratios

S. No.	Depth of cut (mm)	C1 (1:100)	C2 (1:50)	C3 (1:30)	C4 (1:25)	C5 (1:20)	C6 (1:15)	C7 (1:10)
1.	0.2	0.02	0.01	0.00	0.00	0.00	0.00	0.00
2.	0.4	0.03	0.02	0.00	0.00	0.00	0.00	0.00
3.	0.6	0.08	0.05	0.01	0.01	0.01	0.01	0.01
4.	0.8	0.40	0.20	0.08	0.04	0.03	0.02	0.02
5.	1.0	0.80	0.50	0.30	0.30	0.20	0.08	0.06

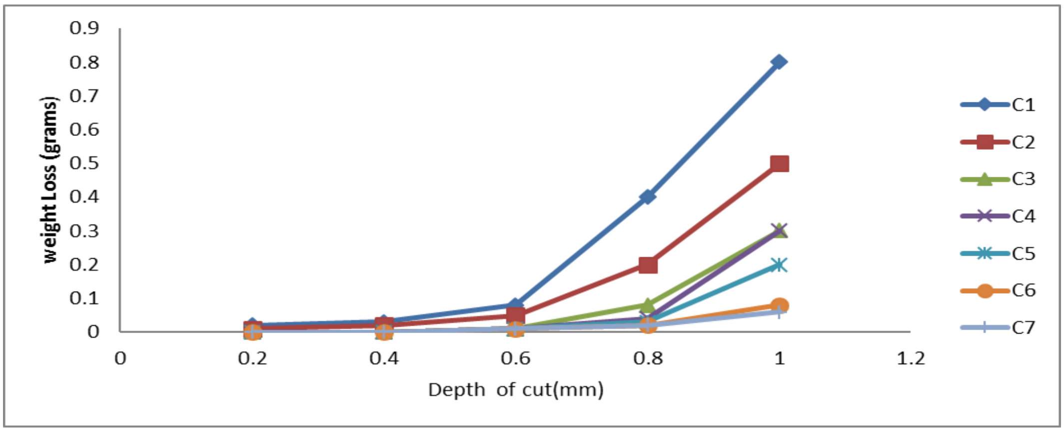

Figure 1: Plot of Weight loss against depth of cut for all the coolant ratios

Fig 1 shows that, for coolant ratio of 1:100(C1) at depth of cut (DOC) of 0.2mm, the cutting tool was observed to wear slightly but immediately, as the volume of application of coolant remained constant. This immediate tool wear must be as a result of decreased lubricity of the mixture. As the depth of cut increased, an almost linear increase in wear was obvious up to a depth of 0.6mm. As the tool dulled remarkably, the area of contact between tool and work piece increased, heat generated due to friction increased, while lubricity was further eroded by the conditions at the cutting point, tool wear was observed to rapidly rise and spike. At 0.8mm to

1.00mm DOC, same condition was observed. In addition to that, it was also noticed that tool breakage and excessive set-up vibrations occurred at these cutting conditions because the cutter was no longer cutting but rubbing even as it attempted to remove more material from the work piece.

With coolant ratio of 1:50 (C2) similar trend as the previous was observed, with slight changes in the quantities of tool wear. At 0.2mm depth of cut (DOC), the cutting tool was observed to wear relatively less than it did with C1 but still immediately as a result of lubricity.

With coolant ratio of 1:30 (C3), it was observed that no immediate wear resulted with a DOC of 0.2mm and 0.4mm, the trend repeated up to a certain degree. Tool wear became obvious only at DOCs of 0.6mm and beyond. Smaller changes in quantity of tool wear, as against the previous conditions, were noticed at DOC 0.6mm-1.0mm, though the rapidity of tool wear was clearly noticed at a DOC of 1.0mm only. This clearly manifests the higher and stabilizing lubricity conditions of the coolant ratio (1:30). Overall tool wear range is far reduced than in previous conditions and even as DOC approached 1.0mm, cutting point integrity was retained considerably.

With coolant ratio 1:25 (C4), the case at C3 repeated itself. The only difference was that Smaller changes in quantity of tool wear, as against the previous conditions, was noticed at DOC 0.4mm-1.0mm though, the rapidity of tool wear increased at DOC of 1.0mm only. Overall tool wear range was far reduced than in previous conditions (0.01-0.04).

According to the graph for C5 (1:20), similar result as that of C4 was observed. Tool wear became obvious only at DOCs of 0.6mm and beyond. Smaller changes in quantity of tool wear, as against the previous conditions, are noticed at DOC 0.4mm-1.0mm. Overall tool wear range was far reduced than in previous conditions (0.01-0.03).

With coolant ratio 1:15(C3), similar result as that of C5 was obtained. In this case, Overall tool wear range is far reduced than in previous conditions (0.01-0.02) and even as DOC approaches values just beyond 1.0mm, cutting point integrity is retained considerably and the finishing was little good however the concentration was not friendly to health.

According to graph of coolant ratio (1:10), no immediate wear resulted with a DOC of 0.2mm and the trend repeated up to a certain degree as the previous coolant ratios. Tool wear became obvious only at DOCs of 0.6mm and beyond. Smaller changes in quantity of tool wear, as against the previous conditions, are noticed at DOC 0.4mm-1.0mm. But tool wear increased as the DOC reduced. This clearly manifests the higher and stabilizing lubricity conditions of the coolant ratio (1:10)Overall tool wear range is far reduced than in previous conditions (0.01-0.02) and even as DOC approaches values just beyond 1.0mm, cutting point integrity is retained considerably and the finishing was little good however the concentration was not also friendly to health.

4. Statistical Analysis of Result

Table IV: Two-Factor Anova without Replication

Summary	*Count*	*Sum*	*Average*	*Variance*
0.2	7	0.03	0.004286	6.19E-05
0.4	7	0.05	0.007143	0.000157
0.6	7	0.18	0.025714	0.000795
0.8	7	0.79	0.112857	0.02009
1	7	2.24	0.32	0.0672
C1	5	1.33	0.266	0.11348
C2	5	0.78	0.156	0.04283
C3	5	0.39	0.078	0.01652
C4	5	0.35	0.07	0.0168
C5	5	0.24	0.048	0.00737
C6	5	0.11	0.022	0.00112
C7	5	0.09	0.018	0.00062

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.501811	4	0.125453	10.27079	5.42E-05	2.776289289
Columns	0.23668	6	0.039447	3.229489	0.018046	2.508188823
Error	0.293149	24	0.012215			
Total	1.03164	34				

This shows that there is a statistical difference between the seven tests (weight loss) carried- out, since the p-values obtained is less than α- value. This clearly shows that depth of cut has a significant effect on the various coolant ratios resulting to different weight loss obtained. A low residual (error) mean square tells us that most variation in the data is accounted for by the separate effects of depth of cuts and coolant ratios. It also shows that from DOCs of 0.2mm and 0.4mm the average is so small when compared to depth of cut from 0.6mm – 1.0mm.In coolant ratio 1:30(C3) there was also a drop of in the average down to coolant ratio 1:10.

Table V: Model Selection and Validation for depth of cut

Components X	**Variance**	**Error**	**R-Sq**
1	0.98417	0.105586	0.73604
2	0.99787	0.041023	0.89744
3	0.99998	0.018603	0.95349
4	1.00000	0.000000	1.00000

The surface response analyses of the study is represented in the figures 2 to 8.

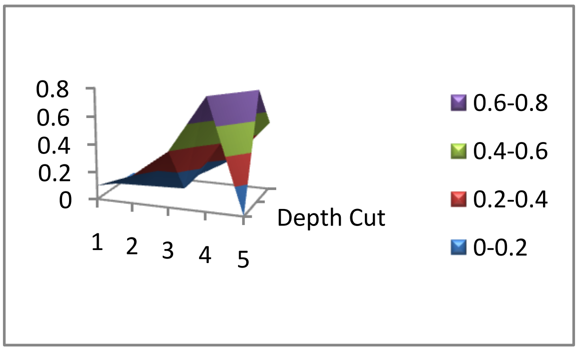

Figure 2: Surface response of depth of cut on 1:100(x_1) and 1:50(x_2)

In fig 2, the surface response indicates that from 0-0.2mm the wear moved slightly on coolant ratios of 1: 100 and 1:50 respectively. As the depth of cut increased the response increased showing the effect of depth of cut on coolant ratio. From 0.4mm-0.6mm and 0.8mm -1.0mm of depth of cut the response increased more and moved geometrically showing that there was excessive wear resulting to frequent regrinding of the cutting tool.

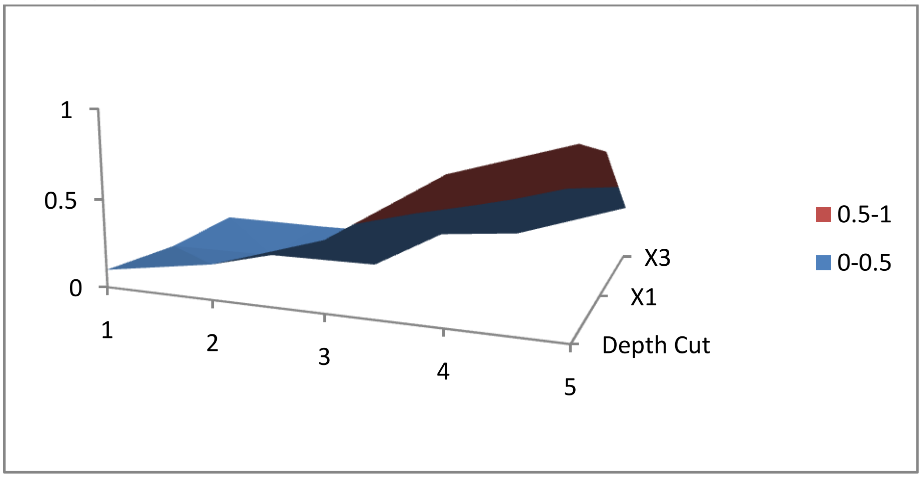

Figure 3: Surface response of depth of cut on 1:100(x_1) and 1:30(x_3)

Fig 3 shows that there was little response of depth of cut on the coolant ratios from 0-0.2mm which was not uniform. From 0.2mm- 04mm depth of cut, the response moved slightly and linearly. In 0.4mm- 0.6mm depth of cut, there was a rapid response showing the effect of depth of cut on the coolant ratios at the point. Likewise from 0.6mm- 0.8mm depth of cut, the response was more rapid when compared to that of 0.4mm – 0.6mm. This clearly shows that as the depth of cut increases the response increases.

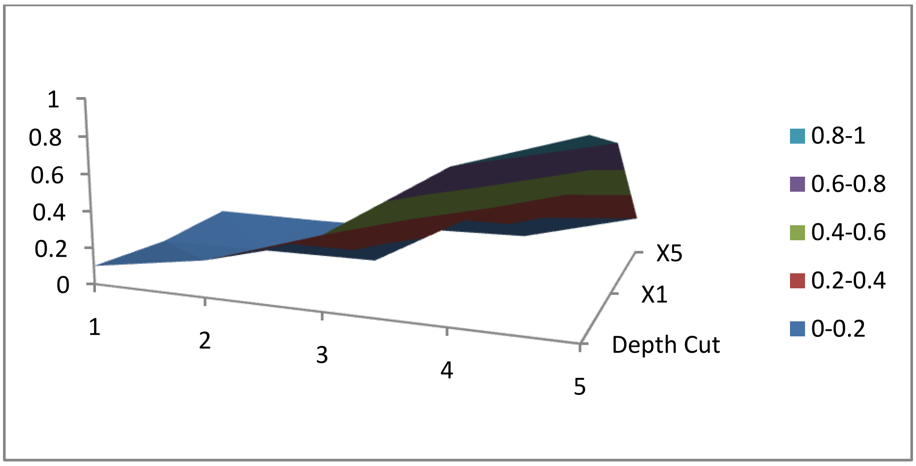

Figure 4: Surface response of depth of cut on 1:100(x_1) and 1:20(x_5)

Fig 4 shows a similar result to that observed in fig 3. Though no immediate surface response resulted with a DOC of 0.2mm but latter moved slightly and was not linear. From 0.2mm -0.4mm there was a little increase of response to a certain degree. The response became more obvious only at DOCs of 0.4mm-0.6mm and beyond. Smaller changes in quantity of response, as against the previous conditions, this clearly manifests lubricity conditions of the coolant ratios (1:100 and1:20).

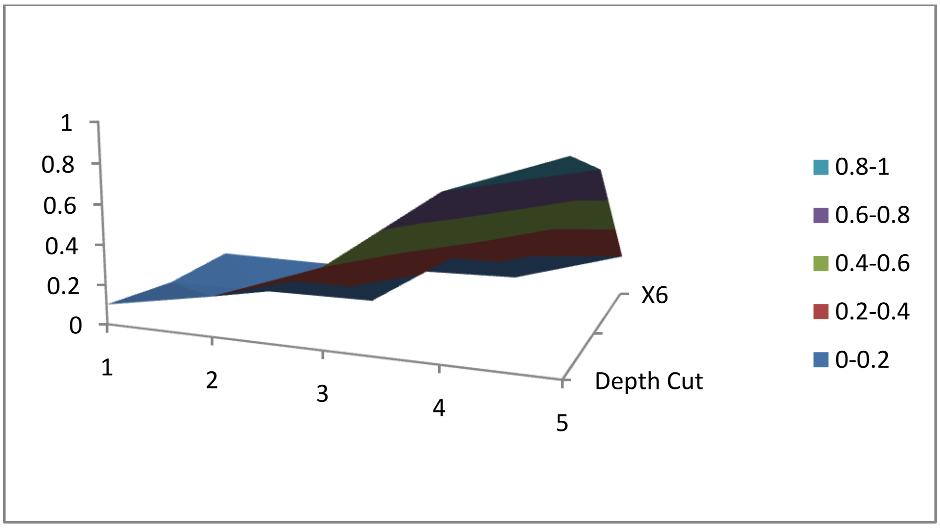

Figure 5: Surface response of depth of cut on 1:100(x_1) and 1:15(x_6)

In fig 5, similar result was observed for coolant ratios of 1: 100 and 1:20 that though no immediate surface response resulted with a DOC of 0.2mm but latter move was not linear. From 0.2mm -0.4mm there was a little increase of response to a certain degree. The response became more obvious only at DOCs of 0.4mm-0.6mm and beyond. Smaller changes in quantity of response, as against the previous conditions (1:100 and 1:50), this clearly manifests lubricity conditions of the coolant ratios (1:100 and1:15).

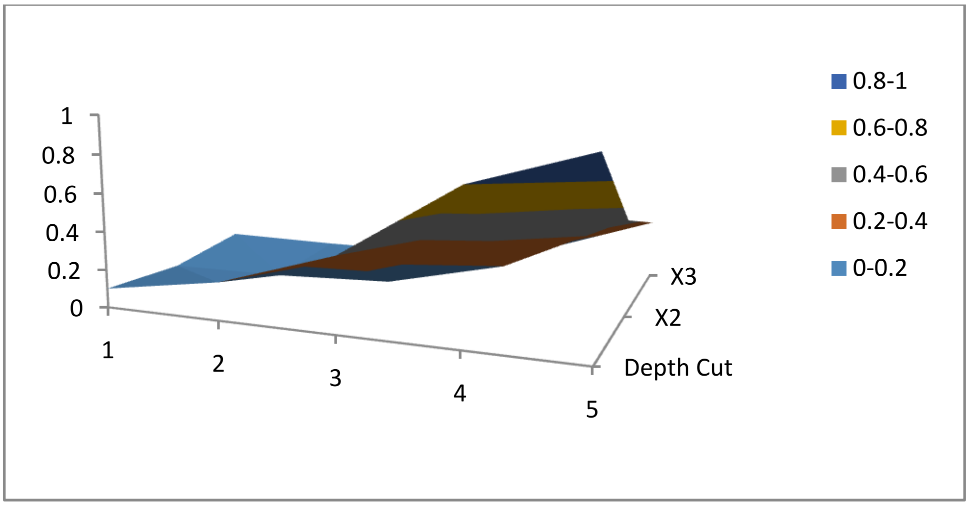

Figure 6: Surface response of depth of cut on 1:50(x_2) and 1:30(x_3)

Fig 6 depicts similar trend as the previous but with slight changes in the response. At a depth of cut (DOC) of 0mm- 0.2mm, the response was observed to be relatively less than those above and was a little linear. As the depth of cut increased, the almost linear trend in response was still obvious up to a depth of 0.2mm-0.4mm. As lubricity was eroded by the conditions at the cutting point, tool response is observed to also rapidly rise at DOC of 0.6mm- 0.8mm and 0.8mm-1.0mm respectively. This is not safe for the operation.

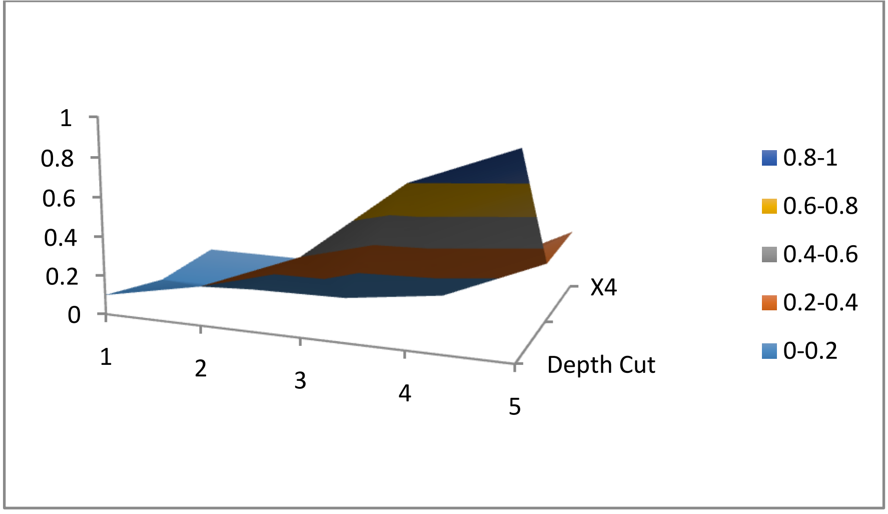

Figure 7: Surface response of depth of cut on 1:30(x_3) and 1:25(x_4)

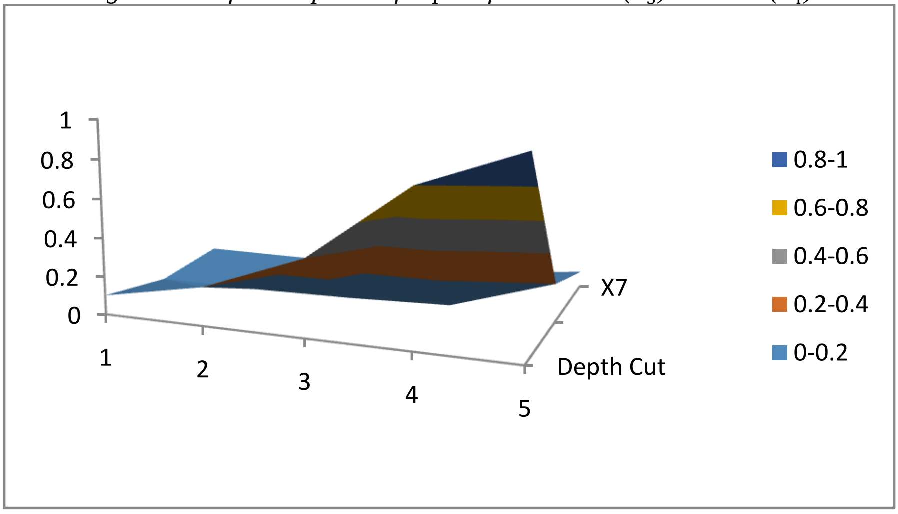

Figure 8: Surface response of depth of cut on 1:15(x_6) and 1:10(x_7)

Fig 7 depicts similar trend as the previous ones but with slight changes in the response. At 0mm- 0.2mm depth of cut (DOC), the response was observed to be relatively less than those of the above. This clearly manifests the higher stability lubricity conditions of the coolant ratios and the response was linear. As the depth of cut increased, the almost linear trend in response is still obvious up to a depth of 0.2mm-0.4mm showing the safe point of the cutting tool. As lubricity is eroded by the conditions at the cutting point, tool response is observed to also rapidly rise at DOC of 0.6mm- 0.8mm and 0.8mm-1.0mm respectively.

Fig 8 shows a case of no changes in the response. At 0mm- 0.2mm depth of cut (DOC), the response was not observed clearly and it was also relatively less when compared to previous ones, which clearly manifests the higher stability lubricity conditions of the coolant ratios and the response was linear. As the depth of cut increased, the almost linear trend in response remained obvious up to a depth of 0.2mm-0.4mm showing the safe point of the cutting tool. As lubricity is eroded by the conditions at the cutting point, tool response is observed to also rapidly rise at DOC of 0.6mm- 0.8mm and 0.8mm-1.0mm respectively. This clearly shows the behaviour of HSS tool on coolant ratios.

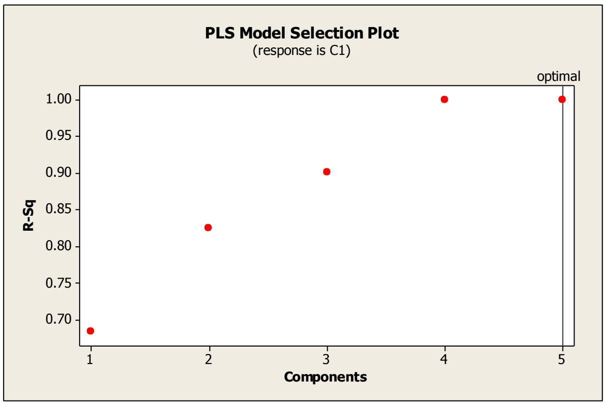

Figure 9: Optimal value plot

In fig 9, for a p- value of 0.05 the R-square is 0.995 which is the optimal value obtained.

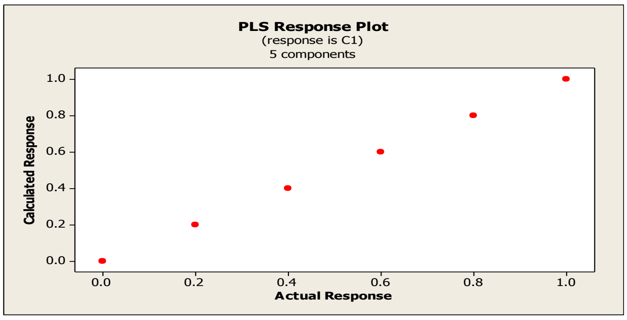

Figure 10: The response plot

The calculated response shows that the experiment was good showing it was linear and equal to one. This means that as the Calculated Response increases the Actual response increases.

5. Conclusion

The aim of the present study was to investigate coolant usage during turning operation of mild steel. From the results and findings of the study, it can be concluded that a maximum depth of cut of 4mm and coolant ratios of 1:30 to 1:10 should be used for HSS tool with specification (14×14×200) mm because it produces relatively no wear in comparison to a DOC of 0.6mm and above. Therefore it is true at that particular optimum depth of cut (0.4mm), a balance between machining time and tool life is achieved.

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