January - February 2020
ISSN: 0193 - 4120 Page No. 7635 - 7644

Investigation on effect of AlCrN & DLC coated Carbide tool in Machining of LM6 aluminum alloy

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Abstract:
Aluminum and its alloys are abundantly available in nature. Since its properties like High strength to weight ratio, Corrosion resistant, Nontoxic and resilient, it plays a dominant role in manufacturing applications. Among the various types of aluminum alloys high silicon alloys where silicon is used as a major alloying element which enhances the mechanical properties further more as high castability, fluidity. These high silicon alloys are used in great wear applications in engine parts such as pistons, cylinders, and cylinder liners and marine applications. Machining this aluminum alloy with conventional carbide tools and high speed tools results in poor surface finish and tool life. Hence in this research turning operation of silumin alloy with coated carbide inserts was attempted. The carbide tool was coated with aluminum chromium nitride (AlCrN) in mid layer and diamond like carbon (DLC) as top layer. The machining conditions were both wet and dry environments. And the responses like average surface roughness, tool life, tool wear and material removal rate have been found and recorded. Subsequently the responses have been logged in the Minitab software and the optimization progression have been done to find out the finest machining amalgamations.

Keywords: *Aluminum Chromium Nitride, Carbide tool, Diamond like carbon High silicon aluminum alloy, Optimization.*

I. INTRODUCTION

Increasing the productivity and quality of the machined parts are the main objective of the manufacturing industries. This involves the process of better handling and management of the machining process. In turning operation control of machining parameters in a precise combination and suitable tool will results in good finish with minimum surface roughness and increased tool life and better material removal rate. Single layer and Multi-layer Coatings are used on the carbide inserts in order to possess high temperature strength, lower fracture toughness.

LM6 aluminium alloy is having 10- 12% silicon which possess high strength to weight proportion and find wide applications (1). Machining LM6 and its allied series of alloys with uncoated tools results in poor tribological outcomes. Carbide tools coated with different materials such as Titanium Nitride (TiN), Titanium Aluminium Nitride (TiAlN), Titanium carbide (TiC) and Diamond Like carbon (DLC) were used for turning the Al-12 Si alloy resulted in better surface finish with increased tool life (2-3). Coolants are used in turning operations to wash away the chips formed, to dissipate the heat and to improve the quality of the work piece (4-5). Proper combination of machining parameters (such as speed, feed rate and depth of cut) with coated tool in machining operation yields least surface roughness, reduced tool wear and maximum material removal rate (6-10). In this work, machining of LM6 alloy with Bi-layered coated carbide tool (AlCrN+ DLC) was performed. And the average surface roughness for each run has been measured. Tool life in minutes has been found using Taylor’s tool life equation and tool wear has been found using profile projector and Rapid-I Vision system. All these values have been recorded in

TEST Engineering & Management

January - February 2020
ISSN: 0193 - 4120 Page No. 7635 - 7644

Minitab statistical software and the optimized values were found for both dry and wet run conditions using response optimiser.

II. Materials and Methods

LM6 aluminum alloy work pieces with dimension of 35 X 100 mm have been used for this investigation. The chemical composition of LM6 alloy was Al 87.62 % with Si 11.3 % found using OES foundry master pro equipment. Aluminum Chromium Nitride and Diamond like carbon coatings were applied over the carbide tool using physical vapor deposition technique. The coating thickness of each material is 2 microns. MTAB (MAXTURN+) CNC turning center machine has been used for machining. The CNC program for machining operation has been programmed in MTS top turn software for different running conditions. Hex sol coolant was used as a lubricant for machining under wet condition.

The machining parameters were taken with 3 levels leading to 27 combinations of experiments.

Table I: Machining Parameters

Parameter	Level 1	Level 2	Level 3
Speed (rpm)	250 0	2750	3000
Feed(mm/rev)	0.08	0.10	0.12
Depth of cut(mm)	0.25	0.50	0.75

The run orders of the machining experiments are as follows:-

Table II: Run Order

Run order	Speed (rpm)	Feed Rate (mm/rev)	Depth of Cut (mm)
1	2500	0.08	0.25
2	2500	0.08	0.5
3	2500	0.08	0.75
4	2500	0.1	0.25
5	2500	0.1	0.5
6	2500	0.1	0.75
7	2500	0.12	0.25
8	2500	0.12	0.5
9	2500	0.12	0.75
10	2750	0.08	0.25
11	2750	0.08	0.5
12	2750	0.08	0.75
13	2750	0.1	0.25
14	2750	0.1	0.5
15	2750	0.1	0.75
16	2750	0.12	0.25
17	2750	0.12	0.5
18	2750	0.12	0.75
19	3000	0.08	0.25
20	3000	0.08	0.5
21	3000	0.08	0.75
22	3000	0.1	0.25
23	3000	0.1	0.5
24	3000	0.1	0.75
25	3000	0.12	0.25
26	3000	0.12	0.5

January - February 2020
ISSN: 0193 - 4120 Page No. 7635 - 7644

27	3000	0.12	0.75

The Mean Roughness (Roughness Average Ra) of the work pieces after the machining process was measured using computerized surface roughness tester. The tool wear after performing the experiments were found using rapid I vision system and the values were compared with profile projector. The tool life and material removal rate have been intended using the Taylor's tool life relation and conventional formulas respectively. The overall responses for all the experimental runs are as follows.

Table III: Responses Recorded – Dry Environment

Dry Environment				
Run order	Ra (µm)	MRR (mm^3/min)	Tool Wear (mm)	Tool life (min)
1	1.9182	5652	0.17	18.09
2	1.8887	11304	0.08	18.09
3	1.5309	16956	0.16	18.09
4	2.1763	7065	0.2	18.09
5	1.6089	14130	0.05	18.09
6	2.0063	21195	0.05	18.09
7	2.2306	8478	0.14	18.09
8	2.3892	16956	0.29	18.09
9	1.6369	25434	0.15	18.09
10	1.4592	6217.2	0.32	14.26
11	1.6308	12434.2	0.1	14.26
12	1.4907	18651.6	0.1	14.26
13	2.0884	7771.5	0.12	14.26
14	1.8973	15543	0.16	14.26
15	2.0577	23314.5	0.17	14.26
16	1.3788	9325.8	0.08	14.26
17	2.0082	18651.6	0.09	14.26
18	1.4	27977.4	0.24	14.26
19	1.4347	6782.4	0.08	11.47
20	1.5269	13564.8	0.02	11.47
21	1.3892	20347.2	0.02	11.47
22	2.206	8478	0.05	11.47
23	1.0139	16956	0.1	11.47
24	1.11	25434	0.11	11.47
25	0.853	10173.6	0.16	11.47
26	2.548	20347.2	0.12	11.47
27	1.1507	30520.8	0.3	11.47

The responses for experiments conducted under wet environment (application of Hex sol lubricant) are as follows.

Table IV: Responses Recorded – Wet Environment

Wet Environment				
Run order	Ra (µm)	MRR (mm^3/min)	Tool Wear (mm)	Tool life (min)
1	1.4211	5652	0.1	18.09
2	0.6601	11304	0.08	18.09
3	0.803	16956	0.09	18.09
4	1.0416	7065	0.01	18.09
5	1.0101	14130	0.11	18.09

6	1.7642	21195	0.11	18.09
7	1.1043	8478	0.13	18.09
8	0.9476	16956	0.13	18.09
9	1.8881	25434	0.12	18.09
10	0.3454	6217.2	0.07	14.26
11	0.7128	12434.2	0.09	14.26
12	1.1462	18651.6	0.1	14.26
13	0.8523	7771.5	0.09	14.26
14	0.9534	15543	0.09	14.26
15	1.3567	23314.5	0.07	14.26
16	1.028	9325.8	0.03	14.26
17	1.5615	18651.6	0.08	14.26
18	1.7743	27977.4	0.02	14.26
19	1.0531	6782.4	0.1	11.47
20	0.6822	13564.8	0.08	11.47
21	1.0938	20347.2	0.12	11.47
22	0.7531	8478	0.08	11.47
23	1.1971	16956	0.05	11.47
24	1.4008	25434	0.08	11.47
25	2.3419	10173.6	0.11	11.47
26	1.6172	20347.2	0.06	11.47
27	1.541	30520.8	0.13	11.47

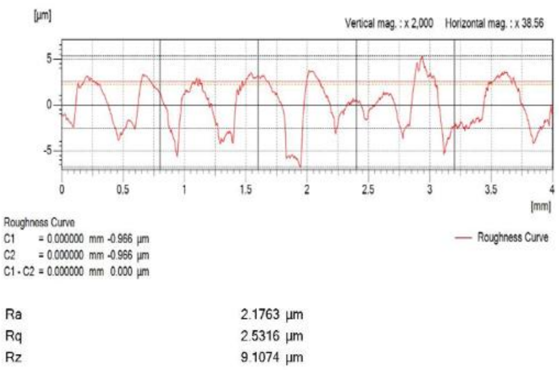

Figure 1: Surface Roughness measured for run order 4 (Dry)

Fig shows the average surface roughness value of 2.1763 μm which has been measured using computerized surface roughness tester for the run order 4th experiment under dry condition.

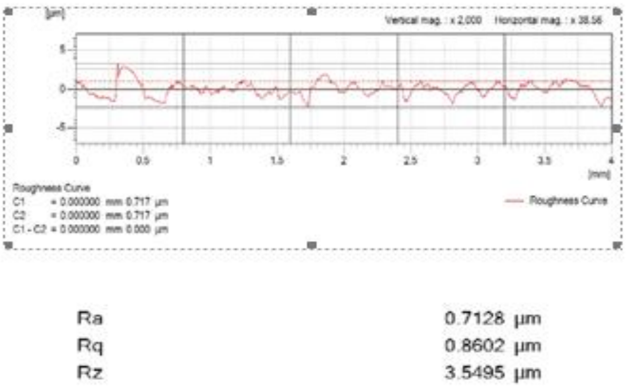

Figure 2: Surface Rouhness for run order 11 (Wet)

Fig shows the average surface roughness value of 0.7128 μm which has been measured using computerized surface roughness tester for the run order 11th experiment under wet condition.

Tool wear measured by the profile projector and from Rapid I vision system images, the wear in coated tool machined under dry environment was more when compared with machined under wet environment.

TEST Engineering & Management

January - February 2020
ISSN: 0193 - 4120 Page No. 7635 - 7644

Figure 3 - Coated tool machined under wet environment

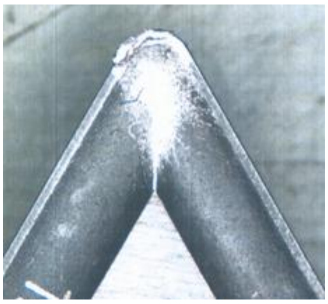

Figure 4 - Coated tool machined under dry environment

III. OPTIMIZATION USING MINI TAB STATISTICAL SOFTWARE

Mini tab is used to analyze different levels of responses in the full factorial design of experiments and there by to find the best optimimum combination of variables for machining LM6 high silicon aluminum alloy. The main effects plots, Interaction plots, optimization plot can be obtained in the minitab software from which multiple inferences may be concluded.

1. Main effect plots – Dry environment

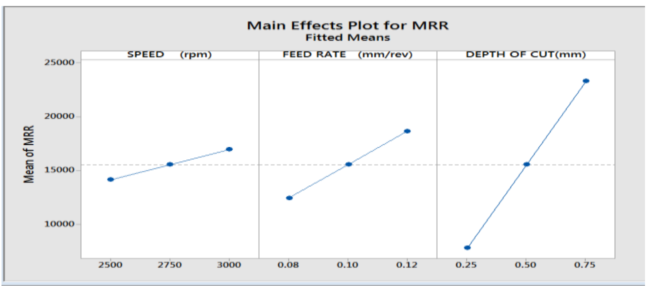

Figure 5: Main Effect plot - MRR

The main purpose of main effect plot is to interpret the results with the known data. From the graph with respect to material removal rate, speed, Feed rate & depth of cut increases, material removal rate also increases.

Figure 6: Main Effect plot - Roughness average

From the above three graphs with respect to surface roughness, when the speed increases average surface roughness value decreases gradually. In case of feed rate and depth of cut, Ra value gets varied slightly (up and down) during machining.

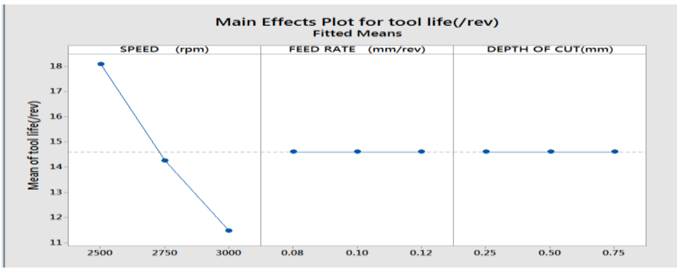

Figure 7: Main Effect plot - Tool life

From the above the graph with respect to tool life,when the speed increases, tool life of the inserts gets decreased. Tool life doesn't depend upon the feed and depth of cut (i.e.) as feed and depth of cut keeps on increasing, tool life is said to be constant.

Interaction plots - Dry environment

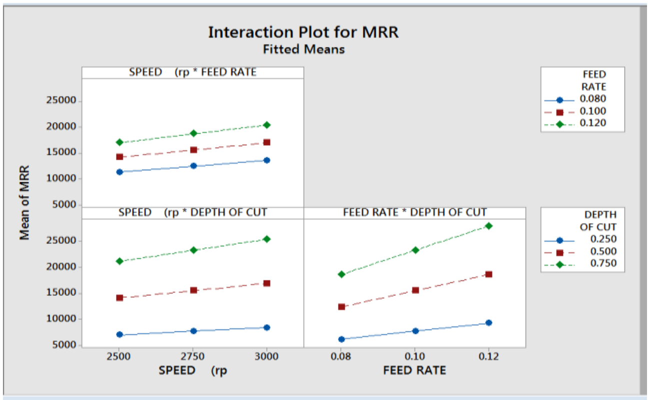

Figure 8: Interaction plot - MRR

Interaction plot is used to deliver association between two factors. From this displayedgraph, the increase in association between the machining variables results in increase in material removal rate.The highest level association between feedrate and depth of cut results in maximum material removal rate.

TEST Engineering & Management

January - February 2020
ISSN: 0193 - 4120 Page No. 7635 - 7644

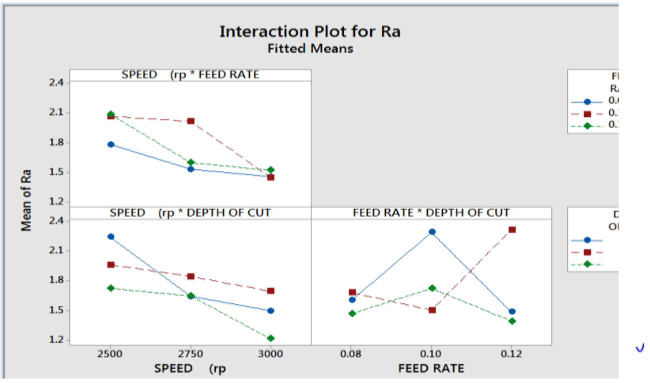

Figure 9: Interaction plot - Roughness Average

From the above graph, the overall association between the machining variables results in both increasing and decreasing fashion. The overall optimum minimum value of mean surface roughness can be obtained under the association of speed and depth of cut in their highest level.

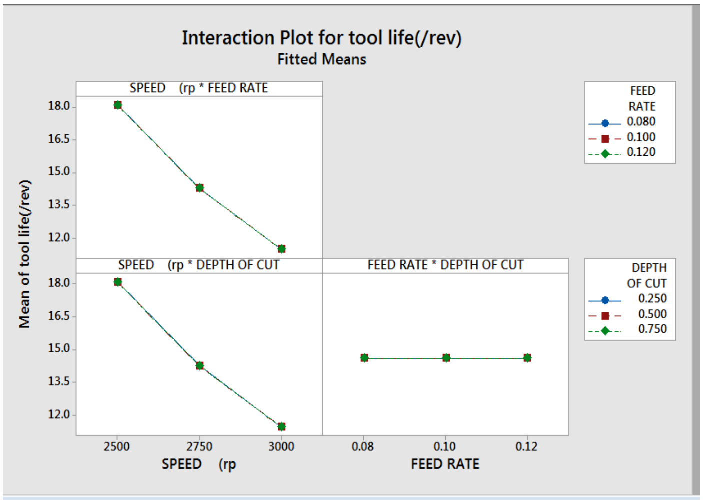

Figure 10: - Interaction plot - tool life

The inference form the above graph is ,the association between speed and feed rate, depth of cut results in similar fashion. When its increases the tool life reaches the minimum value. The association between feed rate and depth of cut doesn't have any effect on tool life.

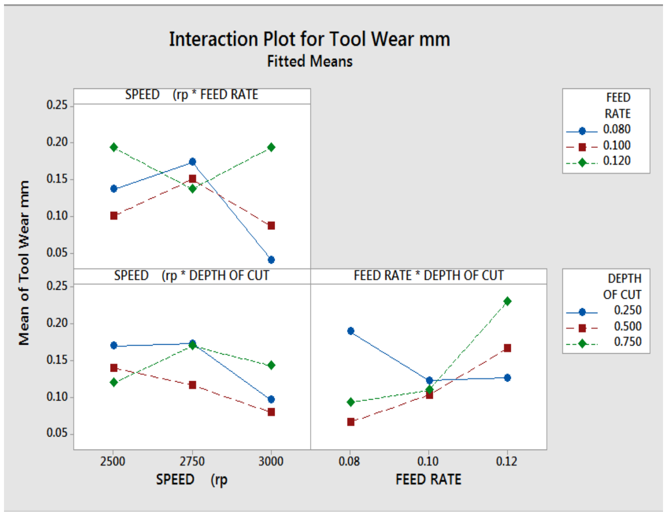

Figure 11: Interaction plot - Tool wear

The inference from the above graph is , the assocaiation between the machining variables results both increasing and decreasing order similarly as in the average surface roughness.The minimum tool wear can be obtained when the speed is 3000 rpm and feedrate is 0.080 mm/rev. And the tool wear is found to be maximum under the relationship as feedrate is 0.12mm/rev and depth of cut as 0.750 mm.

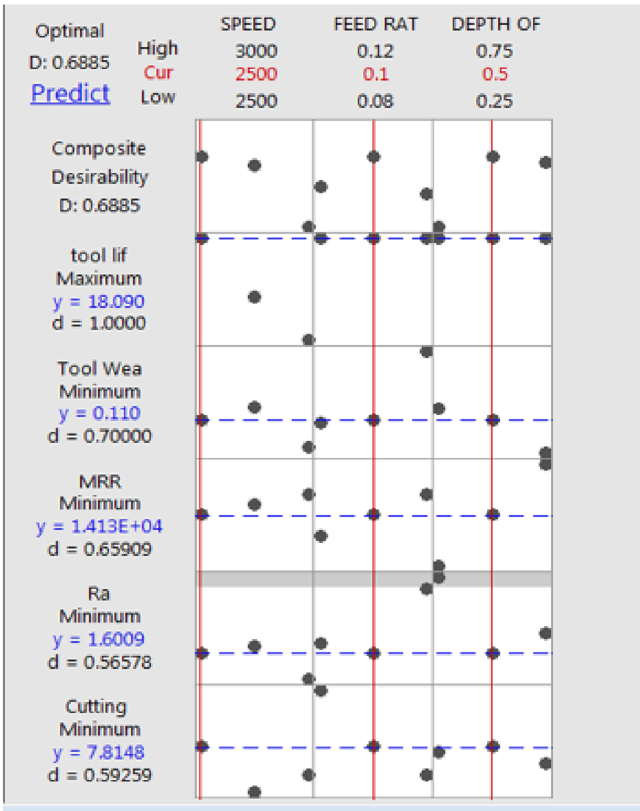

Figure 12: Optimization plot for dry environment

TEST Engineering & Management

January - February 2020
ISSN: 0193 - 4120 Page No. 7635 - 7644

The desirability for the statistical data were given as to achieve maximum tool life and material removal rate and minimum mean surface roughness, cutting time and tool wear. After the analysis the best outcome in machining with coated tool under dry environment were found to be in speed of 2500 rpm, feed rate of 0.1 mm/rev and depth of cut as 0.5mm among the permutations.

Optimization - Machined under wet environment conditions

Main effects plots

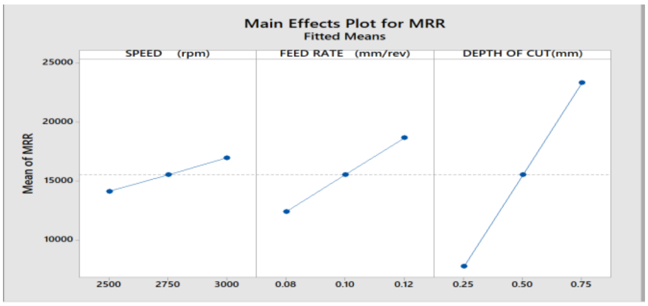

Figure 13: Main effect plot - MRR

From the above graph with respect to material removal rate, the inference was said to be when speed and feed rate increases, material removal rate also increases. In case of increase in depth of cut material removal rate increases rapidly.

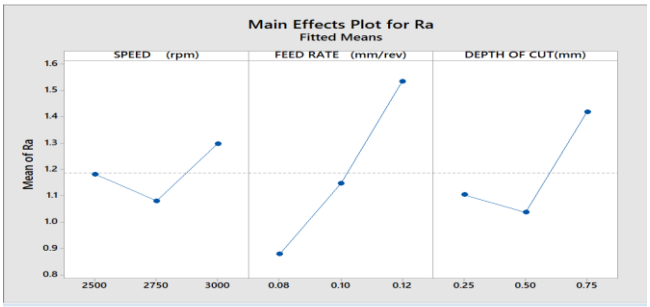

Figure 14: Main Effect Plot - Roughness Average

From the graph with respect to surface roughness, when the speed and depth of cut increases, average surface roughness value initially decreases and then gradually raises. For increase in feed rate, the surface roughness value increases gradually.

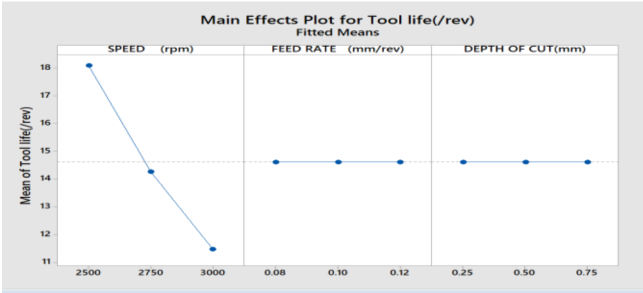

Figure 15: Main Effect plot - Tool Life

From the above graph with respect to tool life, when the speed increases, tool life of the inserts gets decreases rapidly and the tool life doesn't depend upon the feed and depth of cut (i.e.) as feed and depth of cut keeps on increasing.

Interaction plot-wet coated

The following are the interaction plots which is used to describe the machining variables association and its effects on various responses recorded machined with coated tool under wet environment.

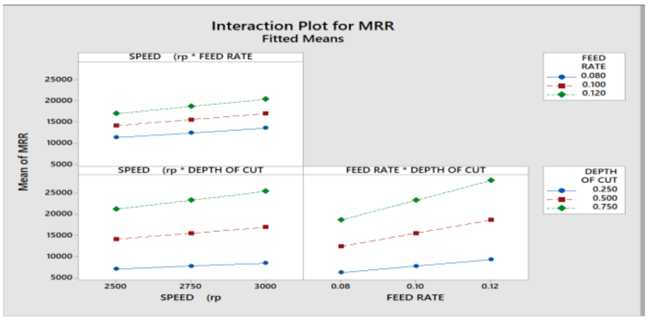

Figure 16: Interaction Plot - MRR

From the above graph, the overall interaction between the variables resulted in increasing fashion. And the highest value of material removal rate can be obtained under feed rate as 0.12 mm/rev with depth of cut as 0.750 mm.

January - February 2020
ISSN: 0193 - 4120 Page No. 7635 - 7644

Figure 17: Interaction plot - Average surface roughness

The inference from the plot above is, the average surface roughness is found to be minimum in two machining conditions. When the feed rate is in the minimum value and depth of cut as 0.5 mm, the association resulted in minimum average surface roughness.

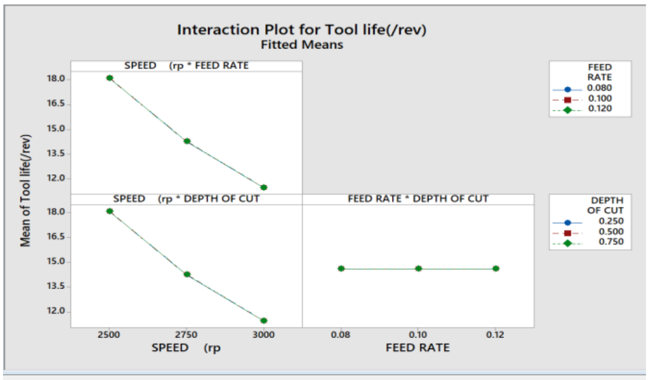

Figure 18: Interaction Plot - Tool life

From this displayed plot, the association between speed with depth of cut and feed rate resulted in decreasing fashion of tool life. The interaction between feed rate and depth of cut doesn't have any effect on tool life.

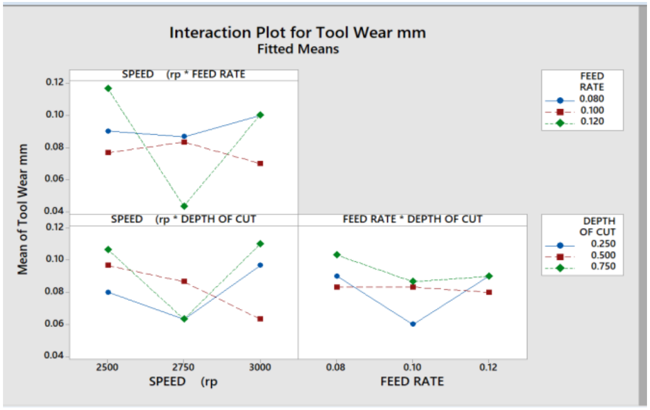

Figure 19: Interaction plot - Tool wear

From the displayed plot, the overall association between the variables resulted in both fashions. The minimum tool wear can be obtained under the interaction of speed as 2750 rpm with feed rate as 0.12 mm /rev.

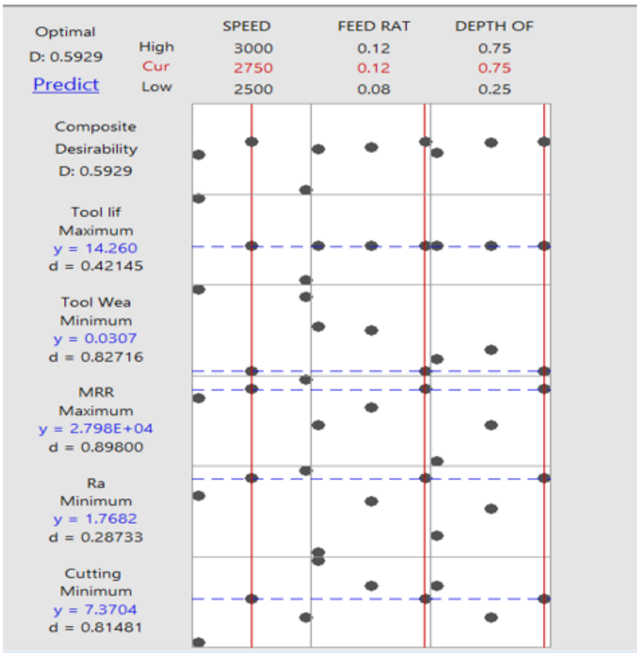

Figure 20: Optimization plot- wet environment

Keeping the desirability same for the responses, the best outcome in machining with coated tool under wet environment were predicted to be in the speed of 2750 rpm, feed rate of 0.12 mm/rev and depth of cut as 0.75mm among the alternatives.

January - February 2020
ISSN: 0193 - 4120 Page No. 7635 - 7644

IV. SEM IMAGES

The SEM Analysis was done to study the surface topography of the coated carbide tools. The High Emissive Scanning Electron Microscope was used for the morphological investigation. The observations were made with following conditions high vacuum environment with 300X magnification.

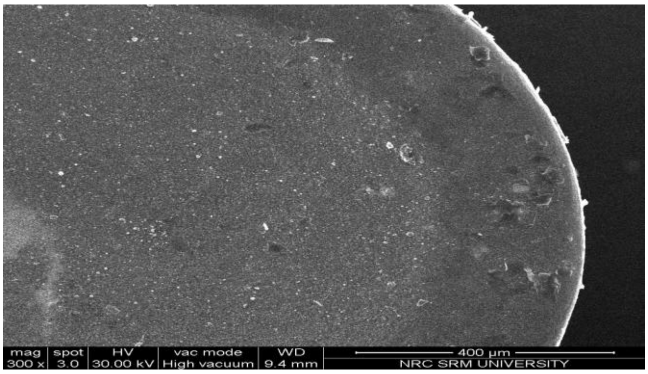

Figure 21: AlCrN coated surface over the carbide tool

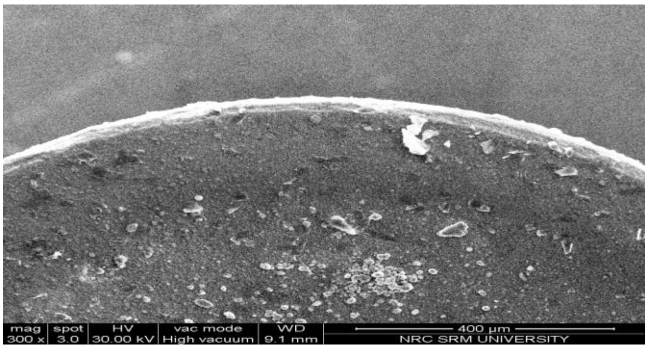

Figure 22: DLC coated surface over the carbide tool

V. CONCLUSION

After the experiments conducted, the various responses have been measured for all 54 runs, machined with coated tool in both dry and wet environment. The optimization process was done in mini tab software to find the best combinations of machining variables. The following conclusion were made

- AlCrN and DLC coated carbide tool possess better wear resistance and resulted in better tribological behavior.
- Machining under wet environment results in smooth surface finish of the work pieces i.e, surface roughness values were found to be minimum compared with dry environment results.
- The optimized values for machining coated tool under dry environment was found to be in speed of 2500 rpm, feed rate of 0.1 mm/rev and depth of cut as 0.5mm among the variations.
- The optimized values for machining coated tool under wet environment was predicted as in be in the speed of 2750 rpm, feed rate of 0.12 mm/rev and depth of cut as 0.75mm among the combinations.

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