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Computer Aided Manufacturing of Titanium (Grade 5) Alloy Part

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ABSTRACT

Titanium alloy (Ti-6Al-4V) Grade 5 have a high strength to weight ratio, very high tensile strength and toughness, corrosion resistance, dimensional stability etc. and these properties are useful for Aerospace, Automobile and Biomedical industries. The industry faces a problem in Ti-Alloy machining; which related to machining parameters, total lead time, Tool wear, CAM strategies, vibrations & surface finish. This paper investigates surface roughness and machining time of titanium alloy (Ti-6Al-4V) using CAM Strategies, Lubrication strategies (Dry, 5%, 10%, 15% coolant and LN_2) Surface roughness were developed based on the response surface method to investigate the machining parameters such as feed rate, tool geometry, nose radius, and machining time. From the experiment affecting the roughness of the surface produced in lubrication strategies 15% and LN_2 process better than dry, 5% and 10%. CAM 3 (Contour Area) gives excellent surface roughness and it also reduced the machining time.

Keywords— Lubrication Strategy, Surface Finish, Titanium Alloy Part, Surface integrity, Ti-6Al-4V, CAM Strategy

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I. INTRODUCTION

Titanium and its alloys used extensively in aerospace of their excellent combination of high specific strength to weight ratio, which is maintained at elevated temperature, their fracture resistance characteristics and their exceptional resistance to corrosion [1]. The Ti-6Al-4V (α-β) offer high toughness, superb corrosion & creep -resistance, bio-capability [2]. It shows useful performance at temperatures up to about 600oc & 60% lighter than general steel. Titanium is very chemically reactive and therefore, has a tendency to weld to the cutting tool during machining, thus leading to chipping and premature tool failure [3].Despite the increased usages and production of titanium alloys, they are expensive when compared to many other metals because of complexity of the extraction process, difficulty of melting and problems that "Machinability of titanium and its alloys" would always be problematic. & matter about techniques are employed to transform this metal into chips" The poor Machinability of titanium and its alloys have lead many large companies (E.g. Rolls-Royce, GE, HAL, India) to invest large sums of money in the developing techniques to minimize machining cost. Reasonable production rates & excellent surface quality can be achieved with non-conventional machining method if the unique characteristics of the metal of its alloys are taken into account.We work on Ti machining by using Unigraphics 8.00 CAM Software & Kennametal tooling to the optimum satisfied level of Ti machining with a study of chip formation techniques, cooling techniques and tool life because nearly 30% tooling cost is directly affect the product cost. This helps to introduce new way of machining of challengeable material like Ti alloys.According to C.T. Olofson, Problems in machining titanium originate from three basic sources: high cutting temperatures, chemical

reactions with tools and relatively low modulus of elasticity. Unlike steel, titanium does not form a built-up edge on tools, and this behavior accounts for the characteristically good surface finishes obtained even at low cutting speeds. Unfortunately, the lack of a built-up edge also increases the abrading and alloying action of the thin chip which literally races over a small tool-chip contact area under high pressures. This combination of characteristics and the relatively poor thermal conductivity of titanium results in unusually high tool-tip temperatures. Titanium's strong chemical reactivity with tool materials at high cutting temperatures and pressures promotes galling and tool wear. Mechanical problems result from titanium's relatively low modulus of elasticity, half that of steel. The low modulus coupled with high thrust forces required at the cutting edge can cause deflections in slender parts. Distortion of that kind creates additional heat, because of friction between the tool and work piece, and problems in meeting dimensional tolerances [4]. As per M Venkata RamanaSurface finish plays vital role in service life of components, to ensure a great reliability of sensitive aeronautical components, surface integrity of titanium alloys should be satisfied. Therefore, it required to optimize parameters like cutting speed, feed and depth of cut while machining titanium components for better surface finish and also high tool life in order to reduce the tool cost. In order to reduce high temperatures in the machining zone, cutting fluids are employed in machining. Cutting fluid improves the surface conditions of the work piece, tool life and the process as a whole. The results have been compared among dry, flooded with Servo cut oil and water and flooded with Synthetic oil coolant conditions. The results show that while machining Ti6Al4V alloy, the Synthetic oil is more effective high cutting speed, high depth of undercut and low feed rate compared to dry and servo cut oil and water conditions [5].
According to Nambia Muthukrishnan application of coolant tends to reduce tool wear and gives a good surface finish compared with dry machining and tool life is improved by 30% .Adhesive wear is observed at the flank portion of the insert on both dry and wet machining. Diffusion wear is more in dry machining [6]. As per Adriano Fagali de Souza Milling is the most important machining process in this industry. Even using updated technologies such as High Speed Milling, which improves the machined surface quality, the hand finishing is still required and it brings some drawbacks such as costs, time and geometrical errors. Today, any CAM software offers some different tool path strategies to milling free form geometries. However, the users must have the know-how to choose the strategies according to geometry complexity, cutting tool geometry and its contact on the machined surface. Choosing an optimum strategy is a rather difficult task to do on the shop floor. The path strategy influences real machining time, polishing time and costs. The results show that the right choice of the tool path can save 88% of the time and 40% of the costs for finishing the mold evaluated, if compared to the less appropriate option [7].

Patil Amit S. has study the various machining problem discussed by different researchers and their probable solution, which helps to reduce tool wear, high surface finish with effective lubrication strategy by reducing machining complexity. The conclusion presented is Lubrication system influences tool life, surface finish and metallurgy of work piece. Cryogenic lubrication with high pressure through spindle gives a segmentation of chip and avoid thermal gradient of cutting tool tip, high pressure easily flown out the chips from cutting area as a result greater surface finish and tool life. Surface finish is directly depends upon machining conditions. Good surface finish obtained at minimum depth of cut, maximum R.P.M., with low cutting speed in wet machining. Dry machining should be avoided for saving tool life and surface texture [8].

II. CAM STRATEGY

According to Ramos et al the adequate choice of a tool path to milling a specific geometry can propitiate a reduction of the production costs and improve the surface roughness. [9]. Besides, the tool path can influence the real machining time due to the amount of acceleration and deceleration involved, and direction alteration of the movements on the machine [10]. Any commercial CAM software today offers several possibilities of the strategies of distributing the tool path in the domain of the designed part. The commonly used tool path distribution strategies are [11-12].
The following strategies are used in UG NX 8.00 CAM EXPRESS for Milling.
Strategy No 1: Floor wall and Rest Milling-

- Floor Wall - It is basically 2D dimensional machining strategies generally using for flat machining it consists of follow cut pattern at 13mm step over at constant radial depth. Tool path are parallel to each other as shown in fig no.1.

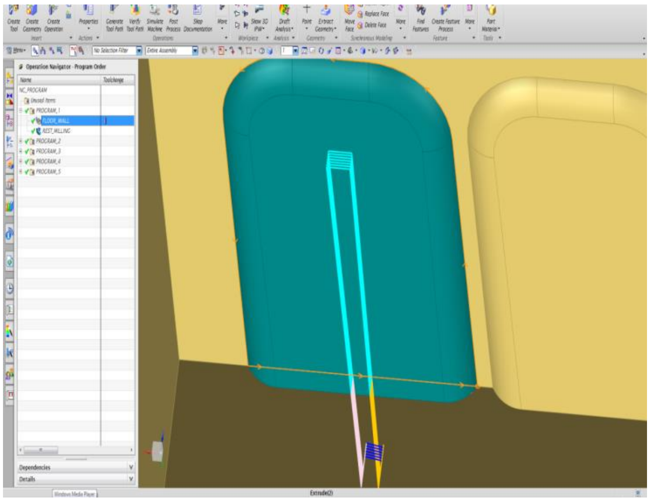


Figure No.1: Floor Wall Milling

- Rest Milling - It is used for removing the material live by the previous method of milling at 3D profile. Fig no.2 shows rest milling tool path in follow cut pattern with 4mm step over. In this way the combination of the above strategy utilizes in pilot experimentation

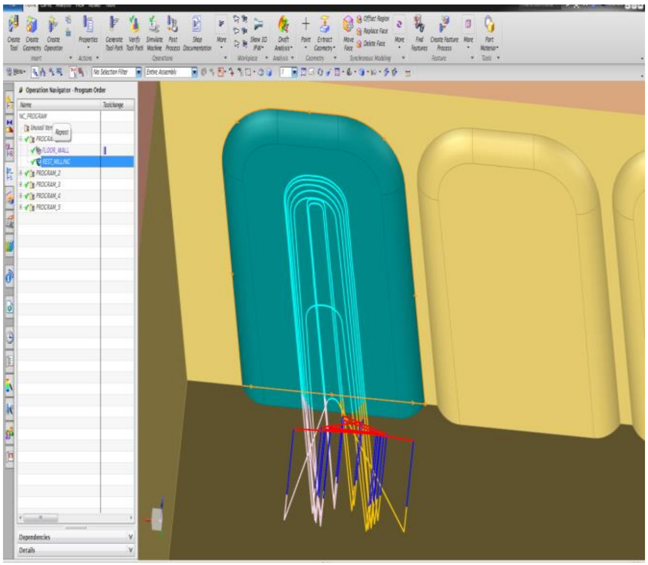


Figure No.2: Rest Milling

Strategy No 2: Cavity milling-

It is a 3D milling Strategy for finishing extruded core portion or variable geometrical complexity cavity parts. In this experiment cavity mill strategy applies to non-steep portion of cavity shown in fig no 3. Tool path lines in flow cut pattern at 10 mm step over are applying for the machine.

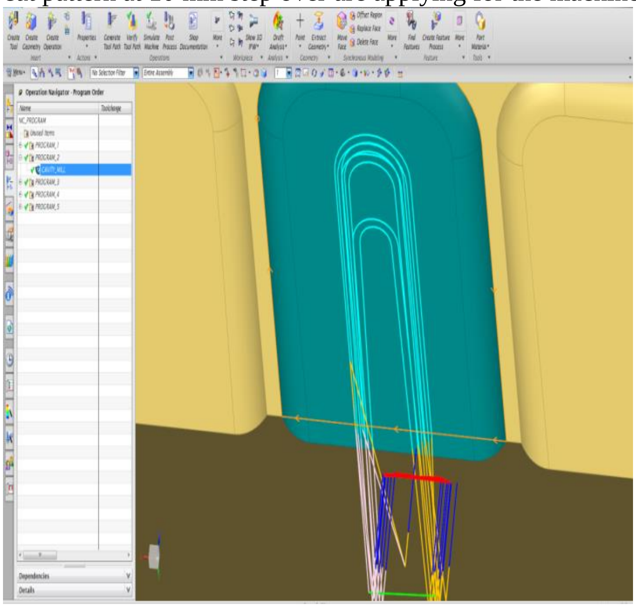


Figure No.3: Cavity milling

Strategy No 3: Contour Area–

This is a popular finishing Strategy for 3D dimensional surface finish only in this statuary tool path driven by geometrix lines of surface and movement of tool through directrix line it is nothing but a cut pattern. Here we used zigzag non-steep cut pattern for non-steep cutting and Z level zigzag steep cut pattern for radial faces shown in fig no.4. In the tool path overlapping distance is minimized, so it gives the optimum utilization of tool path at each travel. In this strategy tool path, making three dimensional nest, which cover selected machining surfaces and covered broken geometries of surfaces.

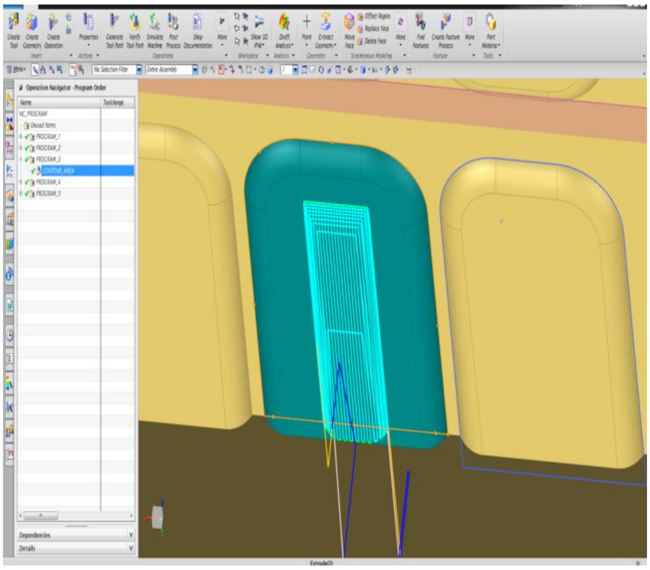


Figure No.4: Contour Milling

Strategy No 4: Stream line –

This Strategy uses flow and cross geometrix and software created tool path flow the combination of this geometrix along with directrix this Strategy recommends for complex shape at control the flow and direction of the smooth control pattern here we used 10 mm step over with flow cut pattern under restricted boundary shown in fig no 5. This strategy strictly three dimensional geometricx

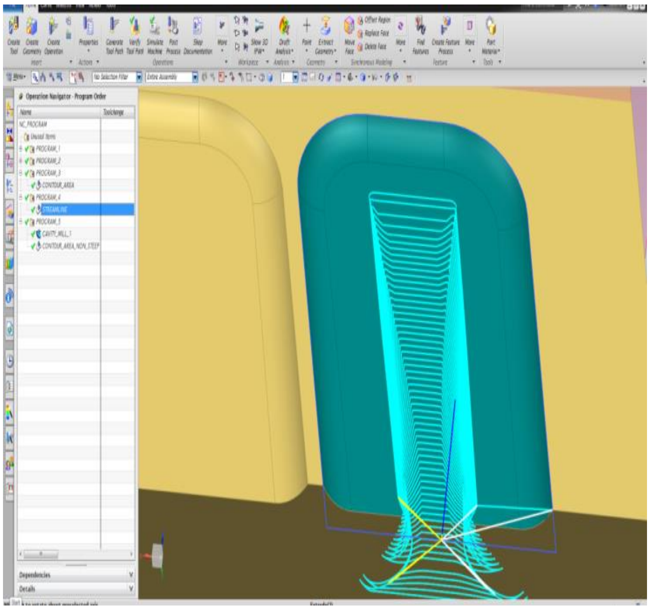


Figure No.5: Steam Line Milling

Strategy No 5: Cavity –Trochoidal Milling + Contour area non Steep-

It is a basically cavity milling Strategy with trochoidal cut pattern at 10 mm step over. Trochoidal milling efficient way to produce 2D or 3D dimensional slot at the bottom surface in this Strategy cutting tool path constant interpolation movement in the direction of providing directrix fig no 6. But this method not suitable for radial curve surfaces at the z-level, it creates a trade mark at z-level vertical wall to remove this we make combination with counter area non steep. We are applying this Strategy with boundary drive method at a constant radial depth of cut in an outward pattern direction (Tool cut the material and movies outward in a radial direction from cutting zone at the end of cutting tool path) Here there is no dwell in feeding. The cutting tool path is connected to the each other as shown in fig no.7. We are using 10 mm steep over throughout this Strategy.

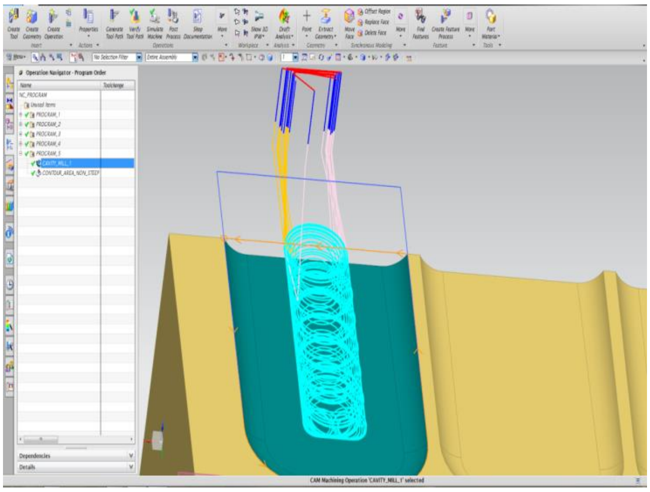


Figure No.6: Cavity –Trochoidal Milling

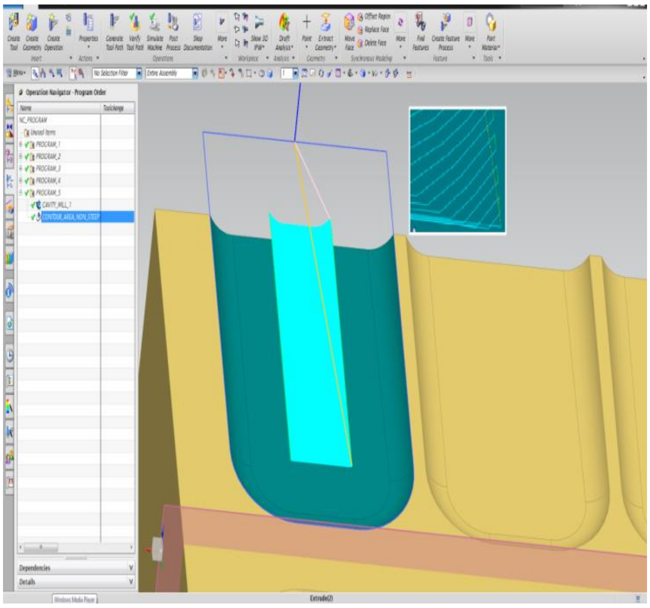


Figure No.7: Contour Area Non Steep Milling

III. LUBRICATION STRATEGIES

Lubrication strategies are important at the time of machining on Ti-6Al-4V hard material. Coolant is used for the reduction in heat produced between tool and work piece at the time of machining and it is an important factor for the reduce tool wear and gives a good surface finish. Lubrication and cooling strategies for titanium machining operations are areas where the cutting process can be improved. The low thermal conductivity of Ti6Al4V causes a concentration of the heat build-up in the cutting zone [9]. At high tool temperatures, typically above 550 ºC, the heat transfer mechanism between the cooling fluid and the tool surface changes to two phase high-speed flow For optimizing the result we used various lubrication strategies are Dry, 5% coolant, 10% coolant, 15% coolant and Liquid Nitrogen (LN_2).

1. Dry lubrication strategy -The jet of air fired through an appropriate spindle, or nozzle, creates a fine atomized layer of air-oil mixture that, on reaching the cutting surface, enables efficient lubrication of the machining process. At the time of dry lubrication strategies heat and friction between tool and material (Ti-6Al-4V) is highly generated. This strategy hasn't given a good surface finish. At the time of machining tool wear is high and it reduced life of the tool. Fig no.8 shows a Dry machining on Ti-6Al-4V material.

Fig No.8: Dry Lubrication Strategy

2. 5% lubrication strategy-
In this strategy the density of oil in water increased by 5%. This strategy gives a good surface finish compared to dry strategy. Tool wear is minimum in this strategy compared to dry machining.

3. 10% lubrication strategy-
In this strategy the density of oil in water increased by 10%. This strategy gives a good surface finish compared to previous two strategies. Tool wear is less in this strategy. Heat generates between tool and Ti-6Al-4v material is low. Vibrations produced at time of machining are low and it is good for machine spindle.

Fig No.9: 10% Lubrication strategy

3. 15% lubrication strategy - In this strategy the density of oil in water increased by 15%. This strategy gives a good surface finish compared to previous strategies. Heat generates between tool and Ti-6Al-4V material is low and tool wear is less and it increased tool life. It reduced machining time and increased production rate.

4. Liquid Nitrogen (LN_2) Strategy - In this strategy we used liquid nitrogen as a coolant whose temperature is -194 ^{0}C. Liquid nitrogen is a colorless clear liquid with a density of 0.807 g/ml. Liquid Nitrogen also called as Cryogenic Machining. Cryogenic machining has several advantages over conventional coolants. LN_2 is allowed to evaporate near the cutting edge of insulated tools, it promotes the dissipation of heat, which otherwise would soften tools and accelerate wear.
Some benefits of LN_2 cooling are as follows:

- Sustainable manufacturing (cleaner, safer and environmentally friendly),
- Increased material removal rate,
- Increased tool life and
- Better machined part surface quality/integrity as compared to previous strategies.

Fig No.10: LN_2 Strategy

IV. DOE FOR CAM STRATEGIES

Table No 1: DOE for CAM Strategies

Trial No.	RPM	Vc m/min	Feed mm	DOC	Coolant	Tool	CAM
1	318	20	76.43	0.1	Dry	THR	1
2	557.32	20	76.43	0.2	5%	THM	2
3	318.47	20	76.43	0.3	10%	HK2000	3
4	318.47	20	76.43	0.4	15%	PA120	4
5	318.47	20	76.43	0.5	LN2	TN450	5
6	398.09	25	87.58	0.2	10%	PA120	5
7	398.09	25	87.58	0.3	15%	TN450	1
8	398.09	25	87.58	0.4	LN2	THR	2
9	605.1	25	87.58	0.5	Dry	THM	3
10	398.09	25	87.58	0.1	5%	HK2000	4
11	636.94	30	95.54	0.3	LN2	THM	4
12	477.71	30	95.54	0.4	Dry	HK2000	5
13	477.71	30	95.54	0.5	5%	PA120	1
14	477.71	30	95.54	0.1	LN2	TN450	2
15	477.71	30	95.54	0.2	Dry	THR	3
16	557.32	35	100.32	0.4	5%	TN450	3
17	557.32	35	100.32	0.5	10%	THR	4
18	668.79	35	100.32	0.1	15%	THM	5
19	557.32	35	100.32	0.2	LN2	HK2000	1
20	557.32	35	100.32	0.3	Dry	PA120	2
21	636.94	40	101.91	0.5	15%	HK2000	2
22	636.94	40	101.91	0.1	LN2	PA120	3
23	636.94	40	101.91	0.2	Dry	TN450	4
24	636.94	40	101.91	0.3	5%	THR	5
25	716.56	40	101.91	0.4	10%	THM	1

V. EXPERIMENTAL SETUP AND PROCEDURE

For the experimental verification of Roughness value**,** we are use following free-form model shown in Fig.11.
All cases investigated were machined by 3 Axes Vertical Milling Center - MAKINO S56. The analysis of surface roughness on the basis of cusp height by using -Mahr surface tester.

Fig No. 11: Mold Ti-6Al-4V (Grade 5) material

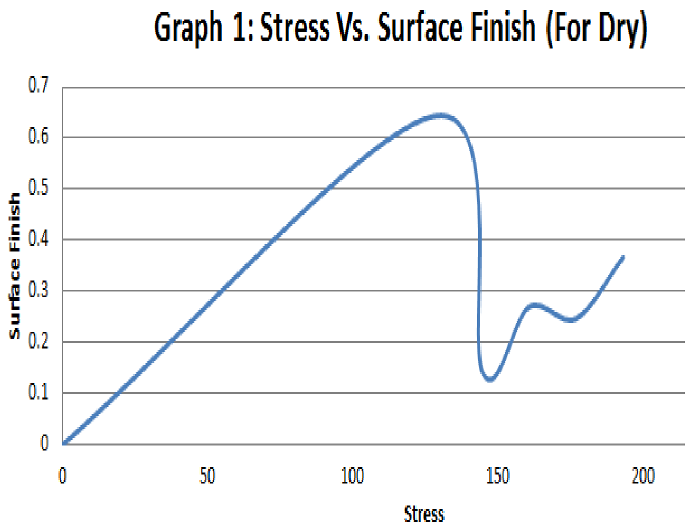
Procedure- The proposed work investigates the efficiency of the different tool path strategy for finishing milling of complex geometries, usually faced in the mold industries. To do so, a mold containing a representative work piece was designed and manufactured for this project. The mold part having 5 cavities designed symmetrically in Fig.11. Due to its symmetrical complexity, this geometry propitiates a possible way to investigate the manufacturing process of a plastic product. The 5 cavities were roughened in the same manner, by 3 axis milling, leaving a uniform amount of material of 0.2 mm, to be removed by the finishing on milling, which was the focus of this study. Each of the 5 cavities was finished by a different tool path strategy. The CAM software UG NX 8 from SIMENSE was used to calculate the tool path under the tolerance zone of 0.01 mm.

VI. STRESS Vs. SURFACE ROUGHNESS (Ra) CURVE

1. For Dry

Table 2: For Dry

Stress	Surface Roughness (Ra) µm
193.28	0.367
176.95	0.247
160.79	0.27
144.783	0.141
128.6	0.644
0	0

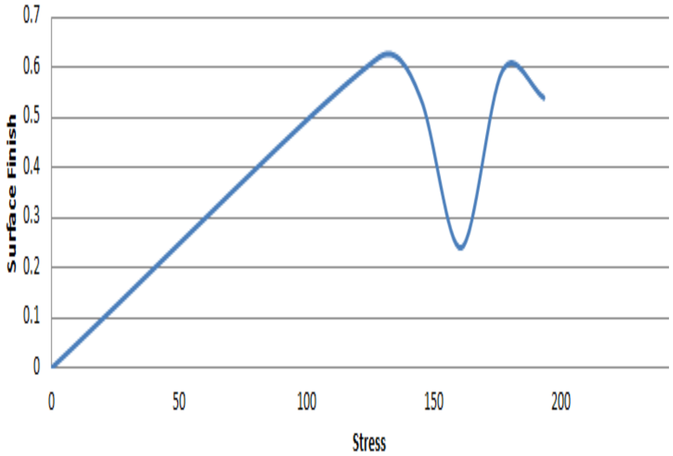


2). For 5 %

Table 3: For 5%

Stress	Surface Roughness (Ra) µm
193.28	0.539
176.95	0.593
160.79	0.24
144.783	0.539
128.61	0.62
0	0

Graph 2: Stress Vs. Surface Finish (For 5%)

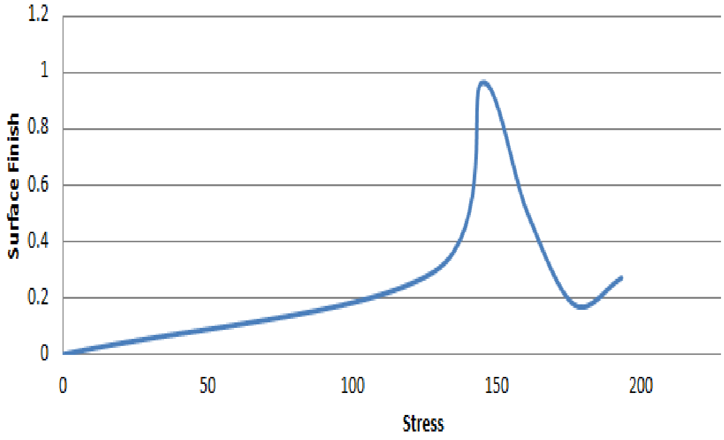


2. For 10%

Table 4: For 10%

Stress	Surface Roughness (Ra) µm
193.28	0.272
176.95	0.176
160.79	0.499
144.783	0.962
128.61	0.295
0	0

Graph 3: Stress Vs. Surface Finish (For 10%)

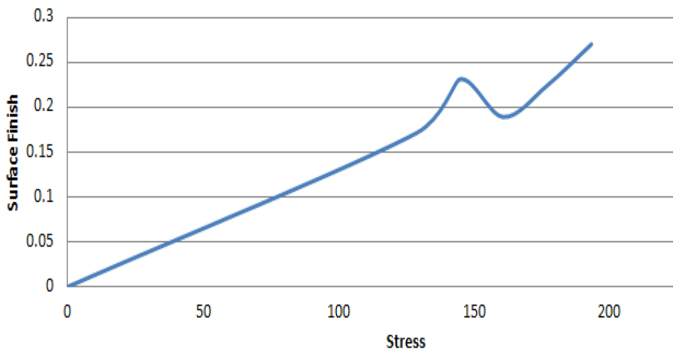


3. For 15%

Table 5: For 15%

Stress	Surface Roughness(Ra) µm
193.28	0.27
176.95	0.224
160.79	0.189
144.783	0.231
128.61	0.171
0	0

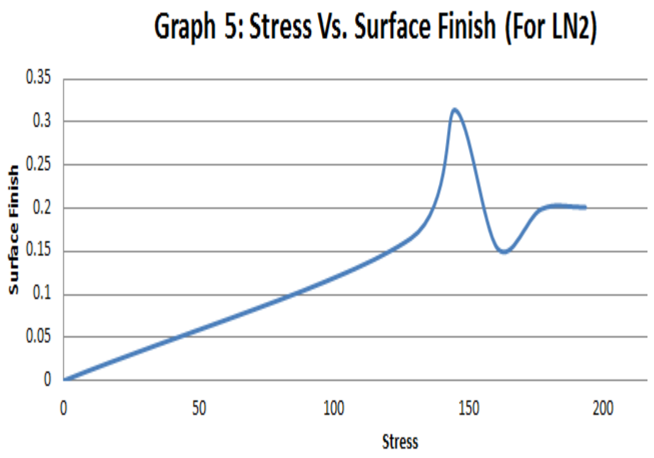
Graph 4: Stress Vs. Surface Finish (For 15%)



4. For LN_2

Table No. 6: For LN_2

Stress	Surface Roughness (Ra) µm
193.28	0.201
176.95	0.199
160.79	0.153
144.783	0.314
128.61	0.165
0	0



VII. RESULT AND DISCUSSION

From reviewing numerous literatures, experimental results are given good CAM strategies, lubricant strategies, surface roughness and reduced machining time or cost for Ti-6Al-4V were identified.

1. CAM Strategies are important factor for Ti-6Al-4V machining to give a better surface finish and it is efficient for reduced machining time. CAM 3 (Contour Area) give a good surface finish with minimum machininig time.
2. Lubricant Strategies are most efficient factor for Ti-6Al-4V machining. Ti-6Al-4V is a hard material and for this material LN_2 (Cryogenic) strategy gives a better result about surface roughness (Ra=0.153), Tool life, machining time etc.
3. From the Stress Vs. surface roughness curve, we conclude that Surface roughness directly depend on stress.
4. The investigations of this study indicate that the cutting parameters like feed rate, CAM strategies, Lubrication strategies and cutting time are the primary influencing factors, which affect surface roughness

VIII. CONCLUSION

This paper presents research on various CAM strategies, Lubrication strategies, cutting parameter, stress, etc. affecting the surface roughness of Ti-6Al-4V material. CAM Strategies investigate the influences of the tool path Strategy on the surface roughness for Ti alloy grade 5. It was assessed by the real machining time, according to tool path strategy, the roughness parameters and the time required for polishing Ti material. All five tool path strategies which slice the part in a horizontal manner (Floor wall and Rest Milling, Cavity milling, Contour Area, Streamline, Cavity –Trochoidal Milling + Contour area non Steep) got the best results. Counter area is the best strategy for reducing time and give the good surface roughness. In lubrication strategies LN_2 strategy gives best result for surface roughness. Stress-surface finish curve shows surface finish is directly depend on longitude stress.

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