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# MACHINABILITY ANALYSIS OF TITANIUM ALLOYS USING DIGRAPH AND MATRIX METHOD FOR COMMON MACHINABLE TOOL INSERTS

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## ABSTRACT

In this research Ti6Al4V in annealed and solution heat treated condition are taken for machinability analysis. The machinability of Ti6Al4V alloys is analyzed using Digraph and Matrix method, with different grades, geometries and load capacity of inserts mainly used in industry. For machinability analysis of alloys, it is found out by conducting slot milling operation with a constant speed, feed and depth of cut for all combination of tool and work piece and the response taken are surface roughness, material removal rate and cutting power. For machinability analysis both round and rectangular geometry inserts of sandvick with grades GCS30T, GC1030 and GC4020 are used.

**KEYWORDS:** Titanium Alloy, Digraph and Matrix Method, Milling Insert, Machinability

## INTRODUCTION

There are many factors affecting machinability, but no widely accepted way to quantify it. Instead, machinability is often assessed on a case-by-case basis, and tests are tailored to the needs of a specific manufacturing process. Common metrics for comparison include tool life, surface finish and tool forces and power consumption [3][4]. Main factor to be chosen for judging machinability depends upon type of operation and production requirement.Machinability means "easiness of machining". The term machinability refers "to the ease with which a metal can be machined (to an acceptable surface finish)". Materials with good machinability require little power to cut, can be cut quickly, easily obtain a good finish, and do not wear the tooling much. The factors that typically improve a material's performance often degrade its machinability. Therefore, to manufacture components economically, engineers are challenged to find ways to improve machinability without harming performance [1]. In this research titanium alloy Ti6Al4V is focused for machinability study. We know titanium alloy Ti6Al4V is very hard to be machined because of the heat generation during machining due to higher friction and hence it produce rapid tool wear, but its superior mechanical and chemical properties compared to other materials make it one of the important aerospace material it accounts for 50% of total titanium production[5]. In this work it mainly focus on machinability analysis of titanium alloys using presently available and commonly used titanium machinable inserts widely used in industry. For machinability analysis Digraph and Matrix method is used.

## PROPERTIES OF TI-6AL-4V

**Table1: Chemical Composition**

| Component | Percentage |
|---|---|
| Ti | 89.55 |
| Al | 6.40 |
| V | 3.89 |
| Fe | 0.16 |
| C | 0.002 |

**Table 2: Mechanical Properties**

| | |
|---|---|
| Hardness (HRC) | 30-38 |
| Yield Strength | 900 Mpa |
| Ultimate Tensile Strength | 950 Mpa |
| Elongation | 14% |
| Poisson"s Ratio | 0.342 |
| Modulus of Elasticity | 113 Gpa |
| Density | 4.43g/cm$^3$ |
| Thermal Conductivity | 6.7 W/m-K |

## CUTTING CONDITIONS

Cutting condition is created by appropriate selection of cutting parameter values corresponding to cutting speed, feed, axial and radial depth of cut. The ranges of cutting parameters are determined using Sandvik coromant tool catalogue. In this study slot milling operation is carried out. In slot milling operation 100% cutter engagement is possible. Therefore we can assess the conditions on any engagement from the result obtained from the experiment. The milling operation is carried out in a wet condition. A 6% soluble oil through coolant system at 1 bar pressure and 12 litre/minute flow rate.

## MACHINE TOOL

The machine tool used in the cutting test was Jyoti EXF 1680 which is a three axis CNC machine. The machine configuration is of fixed bed moving column and its spindle is delivering a maximum torque of 472-712Nm depending upon the load condition. With its high torque motor and gearbox the table size of machine is 2000mm×800mm and its working volume is 1600mm×800mm8×00mm. the machine is installed with Siemens 840D-SL controller with updated machining cycles. This machine complies with VDI/DGQ 3447 standard and maintains its positional uncertainty within 0.001mm and repeatability within 0.005mm. shopmill software is installed in the machine.

**Figure 2: 3 Axis Machining Centre**

**Work Piece**

The work piece material used in the machining test was Ti6Al4V in material heat treated annealed conditions.

- **Work piece Dimension**

140mm×30mm×27mm (annealed condition) & 330mm×30mm×30mm (solution heat treated condition)

**Figure 3: Machined Work Piece**

## EXPERIMENTAL DESIGN FOR MACHINABILITY ANALYSIS

**Table 3: Cutting Condition Used For Machinability Analysis**

| | |
|---|---|
| Spindle Speed (rpm) | 382 |
| Feed Rate(mm/min) | 80 |
| Depth of Cut(mm) | 1.5 |

## TOOL INSERTS USED FOR MACHINABILITY ANALYSIS

**Table 4: Inserts Used For Machinability Analysis**

| Insert Grade | Insert Geometry |
|---|---|
| PL GC1030 | Round |
| PM GC1030 | Rectangular |
| PM GC4020 | Round |
| PM GC4020 | Rectangular |
| PL GCS30T | Round |
| PL GCS30T | Rectangular |

PL-Light Load, PM-Medium Load

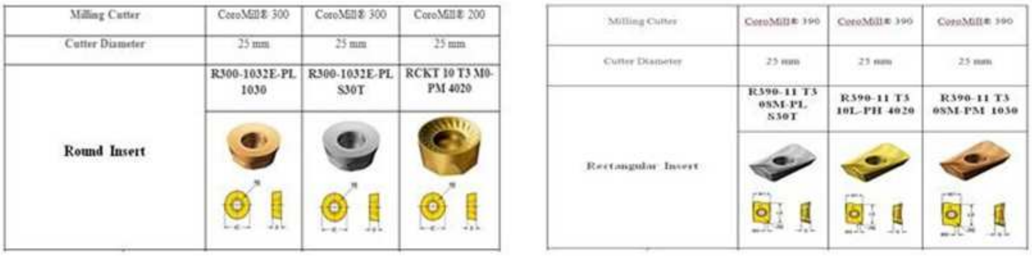


**Figure 4: Milling Cutter Inserts Used For Machinability Analysis**

## MACHINABILITY ANALYSIS OF Ti6Al4V USING DIGRAPH & MATRIX METHOD

A methodology for the machinability evaluation of work materials for a given machining operation is suggested on the basis of the digraph and matrix methods.

Identify the machinability attributes for the given machining operation and shortlist the work materials that satisfy the operation requirements. In addition, also consider relative importance between the attributes. Obtain the values of the attributes *(Di)* and their relative importance‟s (aij). Refer to Tables 5 and 6 for details.

## ATTRIBUTE (Di) VALUE CALCULATION

**Table 5: Value of Machinability Attributes (Di)**

| Class Description | Relative Importance of Attributes | |
|---|---|---|
| | Au | Aj = 10- Au |
| Two attributes are of equal importance | 5 | 5 |
| One attribute is slightly more important than the other | 6 | 4 |
| One attribute is more important than the other | 7 | 3 |
| One attribute is much more important than the other | 8 | 2 |
| One attribute is extremely more important than the other | 9 | 1 |
| One attribute is exceptionally more important than the other | 10 | 0 |

**Table 6: Relative Importance of Machinability Attributes ($A_{ij}$)**

| Qualitative Measure of Machinability Attribute | Assigned Value of Machinability Attribute (Di) |
|---|---|
| Exceptionally low | 0 |
| Extremely low | 1 |
| Very low | 2 |
| Below average | 3 |
| Average | 4 |
| Above average | 5 |
| Moderate | 6 |
| High | 7 |
| Very high | 8 |
| Extremely high | 9 |
| Exceptionally high | 10 |

Attribute Value Equation for ***Smaller the best***

$$Di = \frac{Aiu - Aii}{Aiu - Ail} \times 10 \qquad (1)$$

Attribute Value Equation for ***Larger the best.***

$$Di = \frac{Aii - Ail}{Aiu - Ail} \times 10 \qquad (2)$$

Where Aii= Corresponding experiment response parameter value, Aiu= Upper value of the experiment response parameter value & Ail= Lower value of the experiment response parameter value

**Table 7: Experiment Results after Machining Ti6al4v (Annealed)**

| Insert Grade | Work Tool Insert Combination / Identification Code | MRR ($Mm^3$/Min) | Surface Roughness-(Ra) (Microns) | Cutting Power (Kw) |
|---|---|---|---|---|
| PLGC1030 | TAGC1030R | 1391 | 0.8 | 0.179 |
| PMGC1030 | TAGC1030S | 1591 | 0.545 | 0.198 |
| PMGC4020 | TAGC4020R | 1398 | 0.27 | 0.18 |
| PMGC4020 | TAGC4020S | 1563 | 0.8 | 0.201 |
| PLGCS30T | TAGCS30TR | 1460 | 0.125 | 0.19 |
| PLGCS30T | TAGCS30TS | 1600 | 0.480 | 0.21 |

**Table 8: Experiment Results After Machining Ti6Al4V (Solution Heat Treated)**

| Insert Grade | Work Tool Insert Combination / Identification Code | MRR ($Mm^3$/Min) | Surface Roughness-(Ra) (Microns) | Cutting Power (Kw) |
|---|---|---|---|---|
| PLGC1030 | TSGC1030R | 1304 | 1.22 | 0.18 |
| PMGC1030 | TSGC1030S | 1448 | 0.71 | 0.201 |
| PMGC4020 | TSGC4020R | 1341 | 0.36 | 0.185 |
| PMGC4020 | TSGC4020S | 1494 | 1.07 | 0.212 |
| PLGCS30T | TSGCS30TR | 1460 | 0.13 | 0.203 |
| PLGCS30T | TSGCS30TS | 1514 | 0.51 | 0.215 |

**Table 9: Machinability Attributes Values (Di) for Experiment on Ti6Al4V**

| Work Tool Insert Combination / Identification Code | Cutting Power | Surface Roughness-Ra | MRR |
|---|---|---|---|
| TAGC1030R | 10 | 4 | 3 |
| TAGC1030S | 6 | 7 | 10 |
| TAGC4020R | 10 | 9 | 4 |
| TAGC4020S | 3 | 4 | 9 |
| TAGCS30TR | 9 | 10 | 6 |
| TAGCS30TS | 2 | 7 | 10 |
| TSGC1030R | 9 | 0 | 0 |
| TSGC1030S | 4 | 5 | 5 |
| TSGC4020R | 9 | 8 | 2 |
| TSGC4020S | 1 | 2 | 7 |
| TSGCS30TR | 7 | 10 | 6 |
| TSGCS30TS | 0 | 7 | 8 |

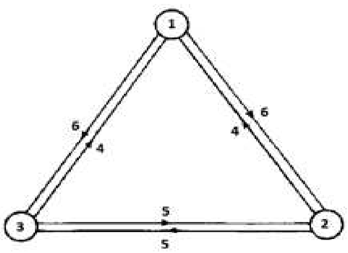


**Figure 5: Universal Machinability Attributes Digraph for Both Machining Experiments Attributes: (1) Cutting Power (CP): (2) Surface Roughness (SR): (3) Material Removal Rate (MRR)**

$$C = \begin{array}{c} \\ PC \\ SR \\ MRR \end{array} \begin{array}{c} \text{Attributes} \\ \\ \\ \\ \end{array} \begin{array}{ccc} PC & SR & MRR \\ \end{array}$$

$$C = \begin{matrix} & PC & SR & MRR \\ PC \\ SR \\ MRR \end{matrix} \begin{pmatrix} D_1 & a_{12} & a_{13} \\ a_{21} & D_2 & a_{23} \\ a_{31} & a_{32} & D_3 \end{pmatrix}$$

**Figure 6: Universal Machinability Attributes Matrix for the Universal Machinability Attributes Digraph**

Universal machinability function for the Universal machinability attributes matrix

= Permanent of Universal machinability attributes matrix =Per(C)

= {D1 × ((D2 × D3) + (a23 × a32))} + {a12 × ((a21 × D3) + (a23 × a31))} + {a13 × ((a21 × a32) + (D2 × a31))} (3)

**Table 10: Universal Machinability Index and Rank of Work Tool Combination**

| Insert Grade | Work Tool Insert Combination / Identification Code | Universal Machinability Index | Rank |
|---|---|---|---|
| PLGC1030 | TAGC1030R | 802 | 7 |
| PMGC1030 | TAGC1030S | 1218 | 3 |
| PMGC4020 | TAGC4020R | 1102 | 4 |
| PLGC4020 | TAGC4020S | 759 | 8 |
| PLGCS30T | TAGCS30TR | 1389 | 1 |
| PLGCS30T | TAGCS30TS | 838 | 6 |
| PLGC1030 | TSGC1030R | 465 | 12 |
| PMGC1030 | TSGC1030S | 680 | 9 |
| PMGC4020 | TSGC4020R | 849 | 5 |
| PLGC4020 | TSGC4020S | 495 | 11 |
| PLGCS30T | TSGCS30TR | 1220 | 2 |
| PLGCS30T | TSGCS30TS | 600 | 10 |

## CONCLUSIONS

After machinability analysis it‟s found that round geometry has better machinability than rectangular one, also GCS30T grade is very efficient grade compared to GC4020 and GC1030 and also GC4020 is better than GC1030 grade. In this research it also finds that as load capacity increases machinability also increases. Comparing machinability of material annealed material have more machinability than solution heat treated material.

**Table 11**

| Rank | Work-Tool Insert Combination |
|---|---|
| 1 | TAGCS30TR |
| 2 | TSGCS30TR |
| 3 | TAGC1030S |
| 4 | TAGC4020R |
| 5 | TSGC4020R |
| 6 | TAGCS30TS |
| 7 | TAGC1030R |
| 8 | TAGC4020S |
| 9 | TSGC1030S |
| 10 | TSGCS30TS |
| 11 | TSGC4020S |
| 12 | TSGC1030R |

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