Experimental Investigation of Cutting Forces and Vibrations in Ti-6Al-4V Machining Under Varying Rake Angles

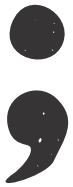
Sushil V. Ingle

DeepScience

Experimental Investigation of Cutting Forces and Vibrations in Ti-6Al-4V Machining Under Varying Rake Angles

Sushil V. Ingle

MET's Institute of Engineering, Adgaon, Nashik, India



DeepScience

Published, marketed, and distributed by:

Deep Science Publishing, 2026
USA | UK | India | Turkey
Reg. No. MH-33-0658412
www.deepscienceresearch.com
editor@deepscienceresearch.com
WhatsApp: +91 7977171947

ISBN: 978-93-7185-424-5

E-ISBN: 978-93-7185-905-9

https://doi.org/10.70593/978-93-7185-905-9

Copyright © Sushil V. Ingle, 2026.

Citation: Ingle, S. V. (2026). *Experimental Investigation of Cutting Forces and Vibrations in Ti-6Al-4V Machining Under Varying Rake Angles*. Deep Science Publishing. https://doi.org/10.70593/978-93-7185-905-9

This book is published online under a fully open access program and is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License (CC BY-NC 4.0). This open access license allows third parties to copy and redistribute the material in any medium or format, provided that proper attribution is given to the author(s) and the published source. The publishers, authors, and editors are not responsible for errors or omissions, or for any consequences arising from the application of the information presented in this book, and make no warranty, express or implied, regarding the content of this publication. Although the publisher, authors, and editors have made every effort to ensure that the content is not misleading or false, they do not represent or warrant that the information-particularly regarding verification by third parties-has been verified. The publisher is neutral with regard to jurisdictional claims in published maps and institutional affiliations. The authors and publishers have made every effort to contact all copyright holders of the material reproduced in this publication and apologize to anyone we may have been unable to reach. If any copyright material has not been acknowledged, please write to us so we can correct it in a future reprint.

Preface

Titanium and its alloys have outstanding corrosion resistance, superior biocompatibility, notable tissue inertness, good weld-ability, and other properties [1, 2]. These alloys have several uses in a variety of industries, including the chemical processing industry, the oil and gas industry, the marine and aviation industries, and the medical sector [3]. The aforementioned intrinsic qualities and practicality of titanium alloys compel researchers to investigate and scrutinize a variety of these alloys' machining features. Recent years have seen increased interest from other commercial and industrial sectors in the studies on the machinability characteristics of these alloys. On the other hand, restricted use of titanium alloys is caused by their high initial cost and extraction process challenges. Additionally, due to lower productivity, these alloys can only be machined at a limited range of cutting rates (about 30-60 m/min) due to their high chemical affinity and poor heat conductivity [2].

Titanium alloys are challenging to manufacture because the thin chips create a small surface area between the cutting tool and the work piece. High cutting temperatures are a result of titanium alloys' inadequate heat conductivity and excessive stress created by the narrow contact area. This study focuses on the optimization of the impact on tool life, surface roughness, crater wear, and flank wear. The process variables for turning Ti-6Al-4V alloy take tool life, surface roughness, crater wear, and flank wear into consideration. Results were analyzed using Taguchi-based SAW, VIKOR, TOPSIS, and Electre techniques. The outcomes of the experiment demonstrate that Ti-6Al4V alloy has been successfully turned using CIMCOOL 360 coolant with a 15% concentration. By selecting the best alternative at cutting speed = 80 rpm, feed rate = 0.18mm/rev, depth of cut = 0.12mm, and rake angle = 14 degrees, where the surface roughness and tool life are, respectively, 0.716µm and 48.3998 min, the research work shows the importance of the suitability of TOPSIS in solving the Multiple Criteria Decision Making (MCDM). From ANOVA results, for surface finish, it is noticed that the process parameter rake angle is having Rank 01 for all levels. Thus rake angle is the major influencing parameter to achieve a better quality of surface roughness. While in the case of flank wear it is crystal clear that process parameter DOC is having Rank 01 for all levels. Thus DOC is the most influencing parameter to achieve lesser flank wear and better quality of tool life.

INDEX

Sr. No. **Page No**

1 INTRODUCTION..... 1-22

1.1 Background.....1
1.2 Motivation.....1
1.3 History of Metal Machining.....2
1.4 Applications and costs of titanium alloys.....3
1.5 Machining.....4
1.6 Titanium Machining.....6
1.7 Machinability of Titanium and its Alloys.....7
1.8 Chip formation and cutting.....7
1.9 Orthogonal cutting.....8
1.10 Wear.....9
1.11 Diffusion.....11
1.12 Basics of diffusion.....13
1.13 Description of chip geometry.....14
1.14 Tool Life.....16
1.15 Analytical methods.....16
1.16 MCDM Methods.....17
1.17 Topsis.....18
1.18 ANNOVA.....19
1.19 SAW Method.....19
1.20 VIKOR Method.....20

1.21 Electre 20
1.22 Scanning electron microscope 20
1.23 ADXL335 Accelerometer 21
1.24 Arduino UNO 21
1.25 Project outline 22

2 Literature Review 23-44

2.1 Background 23
2.2 Influence of the Tool Angles 24
2.3 Rake angles 24
2.4 Tool Wear Types 25
2.5 The interaction between chips & cutting tool during machining of titanium alloys 27
2.6 Titanium Alloy overview 30
2.7 Force Measurement an overview 31
2.8 MCDM Methods for Optimization of Process parameters 37
2.9 Research GAP 43
2.10 Problem Statement 43
2.11 Research Objectives 44

3 Application of Sensors & Arduino 45-49

3.1 Vibration sensing and amplification by ADXL335 45
3.1.1 Three Dimensional Measurements 46
3.1.2 Performance 46
3.1.3 Setting the Bandwidth 47
3.1.4 Noise Consideration 47
3.2 Vibratory Signal Acquisition Using Arduino 47
3.2.1 Process for Circuit Building 48
3.3 Programming in Arduino 49

4 METHODOLOGY 50-59

4.1 Experimental Setup 50
4.2 Tool & Tool Holders 53
4.3 Modification in tool Holder 55
4.4 Coolant 56
4.5 Machining Parameters 57
4.6 Design of Experiments 58

5 Results & Discussion 60-87

5.1 Analysis of Performance 60
5.2 Taguchi method 63
5.2.1 Optimum cutting conditions for Performance parameter 63
5.3 Confirmation Test 68
5.4 Results of Vibration 73
5.5 ANOVA 79
5.6 Tool Life 80
5.7 Surface Roughness 81
5.8 Flank & Crater wear 81
5.9 Conclusions 84

References ..... A-I

APPENDIX – A ..... K-L
APPENDIX – B ..... M-Y
APPENDIX – C ..... Z-LL

Nomenclature

γ -	Rake angle
α -	Clearance angle
Fc-	Cutting force
*F*f -	Feed force
*F*p -	Back force
D -	Diffusion coefficient
J -	Diffusion flux of titanium
C-	Concentration
t -	Time
∇ -	Gradient operator
MCDM -	Multi-criteria decision making
OA –	Orthogonal array
TGRA –	Taguchi-based grey relational analysis
DFA –	Desirability function analysis
PCA –	Principal component analysis
GA –	Genetic algorithm
PSO –	Particle swam optimization
SA –	Simulated annealing
ANN –	Artificial neural network
ASTM –	American society for testing materials
MOORA-	Multi-Objective Optimization by Ratio Analysis.
TOPSIS –	Technique for order performance by similarity to ideal solution.
SAW –	Simple additive weighting.
VIKOR –	Vlekriterijumsko K Ompromisno Rangiranje
ELECTRE –	Elimination and choice Expressing Reality

CNC –	Computer Numerical control
AC –	Air Conditioner.
ADXL335-	Accelerometer (Three axis Sensor)
DNMG –	A Diamond shaped turning inserts with a 55 degree angle.
PVD –	Physical vapor deposition
V_c -	Cutting Speed
T –	Tool life.
C –	Taylor's constant
F –	Feed rate
DOC –	Depth of cut
n -	Constant for tool life
m -	Constant for feed rate
V^+ -	Ideal best
V^- -	Ideal worst
S_i^+ -	Euclidean distance from the ideal best
S_i^-	Euclidean distance from the ideal worst
P_i -	Performance score