

Lecture Notes in Mechanical Engineering

Ravipudi Venkata Rao  
Jan Taler *Editors*

# Advanced Engineering Optimization Through Intelligent Techniques


Select Proceedings of AEOTIT 2022

 Springer

# Lecture Notes in Mechanical Engineering


## Series Editors

Fakher Chaari, National School of Engineers, University of Sfax, Sfax, Tunisia

Francesco Gherardini , Dipartimento di Ingegneria “Enzo Ferrari”, Università di Modena e Reggio Emilia, Modena, Italy

Vitalii Ivanov, Department of Manufacturing Engineering, Machines and Tools, Sumy State University, Sumy, Ukraine

## Editorial Board

Francisco Cavas-Martínez , Departamento de Estructuras, Construcción y Expresión Gráfica Universidad Politécnica de Cartagena, Cartagena, Murcia, Spain

Francesca di Mare, Institute of Energy Technology, Ruhr-Universität Bochum, Bochum, Nordrhein-Westfalen, Germany

Mohamed Haddar, National School of Engineers of Sfax (ENIS), Sfax, Tunisia

Young W. Kwon, Department of Manufacturing Engineering and Aerospace Engineering, Graduate School of Engineering and Applied Science, Monterey, CA, USA

Justyna Trojanowska, Poznan University of Technology, Poznan, Poland

Jinyang Xu, School of Mechanical Engineering, Shanghai Jiao Tong University, Shanghai, China

**Lecture Notes in Mechanical Engineering (LNME)** publishes the latest developments in Mechanical Engineering—quickly, informally and with high quality. Original research reported in proceedings and post-proceedings represents the core of LNME. Volumes published in LNME embrace all aspects, subfields and new challenges of mechanical engineering.

To submit a proposal or request further information, please contact the Springer Editor of your location:

**Europe, USA, Africa:** Leontina Di Cecco at [Leontina.dicecco@springer.com](mailto:Leontina.dicecco@springer.com)

**China:** Ella Zhang at [ella.zhang@springer.com](mailto:ella.zhang@springer.com)

**India:** Priya Vyas at [priya.vyas@springer.com](mailto:priya.vyas@springer.com)

**Rest of Asia, Australia, New Zealand:** Swati Meherishi at [swati.meherishi@springer.com](mailto:swati.meherishi@springer.com) Topics in the series include:

- Engineering Design
- Machinery and Machine Elements
- Automotive Engineering
- Engine Technology
- Aerospace Technology and Astronautics
- Nanotechnology and Microengineering
- MEMS
- Theoretical and Applied Mechanics
- Dynamical Systems, Control
- Fluid Mechanics
- Engineering Thermodynamics, Heat and Mass Transfer
- Manufacturing
- Precision Engineering, Instrumentation, Measurement
- Tribology and Surface Technology

**Indexed by SCOPUS and EI Compindex.** All books published in the series are submitted for consideration in Web of Science.

To submit a proposal for a monograph, please check our Springer Tracts in Mechanical Engineering at <https://link.springer.com/bookseries/11693>

Ravipudi Venkata Rao · Jan Taler  
Editors

# Advanced Engineering Optimization Through Intelligent Techniques

Select Proceedings of AEOTIT 2022

 Springer

*Editors*

Ravipudi Venkata Rao  
Department of Mechanical Engineering  
Sardar Vallabhbhai National Institute  
of Technology  
Surat, India

Jan Taler  
Department of Energy, Faculty  
of Environmental and Energy Engineering  
Politechnika Krakowska (Cracow  
University of Technology)  
Cracow, Poland

ISSN 2195-4356

ISSN 2195-4364 (electronic)

Lecture Notes in Mechanical Engineering

ISBN 978-981-19-9284-1

ISBN 978-981-19-9285-8 (eBook)

<https://doi.org/10.1007/978-981-19-9285-8>

© The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature Singapore Pte Ltd. 2023

This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors, and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd. The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

# Conveners

Dr. D.Sc. Ravipudi Venkata Rao, Professor (HAG), Department of Mechanical Engineering, Sardar Vallabhbhai National Institute of Technology, Surat, India  
Dr. D.Sc. Jan Taler, Senior Professor, Department of Energy, Cracow University of Technology, Cracow, Poland

## International Advisory Committee

Dr. Dan Simon, Cleveland State University, USA  
Dr. A. Gunasekaran, California State University, USA  
Dr. Daizhong Su, Nottingham Trent University, UK  
Dr. Atulya Nagar, Liverpool Hope University, UK  
Dr. D.Sc. Pawel Oclon, Cracow University of Technology, Poland  
Dr. Leandro S. Coelho, Pontifícia Universidade Católica do Paraná, Brazil  
Dr. Viviana C. Mariani, Pontifícia Universidade Católica do Paraná, Brazil  
Dr. Joze Balic, University of Maribor, Slovenia  
Dr. Franc Cus, University of Maribor, Slovenia  
Dr. V. S. Kovalenko, National Technical University of Ukraine, Ukraine  
Dr. S. H. Masood, Swinburne University of Technology, Australia  
Dr. Syed J. Sadjadi, Iran University of Science and Technology, Iran  
Dr. Husam I. Shaheen, Tishreen University, Syria  
Dr. David K. H. Chua, National University of Singapore, Singapore  
Dr. Manukid Parnichkun, Asian Institute of Technology, Thailand  
Dr. H. T. Luong, Asian Institute of Technology, Thailand  
Dr. Samuelson W. Hong, Oriental Institute of Technology, Taiwan  
Dr. Liang Gao, Huazhong University of Science and Technology, China  
Dr. V. K. Jain, MANIT, Bhopal, India  
Dr. P. V. Rao, IIT Delhi, India  
Dr. J. Ramkumar, IIT Kanpur, India  
Dr. Amit Agrawal, IIT Bombay, India

Dr. S. Chakraborty, Jadavpur University, India  
Dr. Manjaree Pandit, MITS Gwalior, India

# Preface

Optimization may be defined as finding the solution to a problem where it is necessary to maximize or minimize a single or set of objective functions within a domain which contains the acceptable values of variables while some restrictions are to be satisfied. There might be a large number of sets of variables in the domain that maximize or minimize the objective function(s) while satisfying the described restrictions. They are called as the acceptable solutions, and the solution which is the best among them is called the optimum solution to the problem. An objective function expresses the main aim of the model which is to be either minimized or maximized. For example, in a manufacturing process, the aim may be to maximize the *profit* or minimize the cost. In designing a structure, the aim may be to maximize the strength or minimize the deflection or a combination of many objectives. The use of optimization techniques helps the engineers in improving the system's performance, utilization, reliability, and cost.

An international conference on “Advanced Engineering Optimization Through Intelligent Techniques (AEOTIT 2022)” was held during January 28–30, 2022, at Sardar Vallabhbhai National Institute of Technology, Surat, India. The objective of the conference was to bring together experts from academic institutions, industries, and research organizations and professional engineers for sharing of knowledge, expertise, and experience in the emerging trends related to advanced engineering optimization techniques and their applications. There had been an overwhelming response to the call for papers. More than 200 research papers were received from the researchers and academicians of the leading institutes and organizations. However, only 66 good-quality papers have been selected based on the recommendations of the reviewers for inclusion in the proceedings. These papers have covered various intelligent optimization techniques including meta-heuristics, neural networks, decision-making methods, and statistical tools.

We are extremely thankful to the authors of the papers, national and international advisory committee members, sessions chairmen, faculty, and staff members of SVNIT, Surat, and CUT, Cracow, and student volunteers for their cooperation and help. We are grateful to the team members of Springer Nature for their support and help in producing these proceedings. We are confident that these proceedings would benefit the optimization research community.

Surat, India  
Cracow, Poland

Ravipudi Venkata Rao  
Jan Taler

# Contents

<b>Process Parameters Optimization by Taguchi Method and Whale Optimization Algorithm of Lathe Turning on EN24 Steel for Prediction of Surface Roughness</b> .....	1
Abhishek Sakat, Amit Sonar, Sanket Ghodake, Rohit Mule, Atul Kulkarni, Prashant Anerao, and Shailendra Ambatkar	
<b>Optimization of TWR and SR of Superalloy Al/9.6B4C in EDM Using Advanced Optimization Techniques</b> .....	11
Neeraj Agarwal and M. R. Singh	
<b>Simulation and Comparative Analysis of Sardar Sarovar Reservoir by Meta-heuristic Algorithm</b> .....	23
Priya Chauhan and S. M. Narulkar	
<b>Determination of Thickness and Refractive Index of Antireflection Coating Thin Films from Reflectivity Spectrum Using Jaya Optimization Algorithm</b> .....	35
Bhautik H. Gevariya, Sanjaykumar J. Patel, and Vipul Kheraj	
<b>Optimization of Worm Gear Drive for Improving Efficiency Using RCGA</b> .....	47
Paridhi Rai and Asim Gopal Barman	
<b>Comparing a Parameterless Technique Jaya with Parameters-Based Evolutionary Algorithms</b> .....	53
Nikita Palod, Vishnu Prasad, and Ruchi Khare	
<b>Optimal Sizing of PV/Wind/Battery Stand-Alone Hybrid Renewable Energy Systems Using TLBO Algorithm</b> .....	65
Ambati Bhimaraju, Ganta Bhanu Ganesh, and Aeidapu Mahesh	

<b>MOJAYA Coupled with R-method for Optimization of Machining Parameters Used in the Generation of Micro Holes on GFRP Composite Using an In-House Developed <math>\mu</math>-ECDM System</b> .....	75
K. V. J. Bhargav, P. Shanthan, P. S. Balaji, and Ranjeet Kumar Sahu	
<b>Enhanced Fruit Fly Optimization Algorithm for Node Capture Attack in WSN</b> .....	87
Rohit Bathla and Priyanka Ahlawat	
<b>Optimization of Construction Scheduling with Rao Algorithm</b> .....	99
Mehmet Yılmaz, Tayfun Dede, and Ravipudi Venkata Rao	
<b>Using Meta-Heuristic Optimization Methods in Solving Time–Cost–Quality Trade-Off Problems</b> .....	107
Mohammad Owais Mohammadi, Tayfun Dede, and Ravipudi Venkata Rao	
<b>A Particle Swarm Optimization-Based Model for Quality–Safety Trade-Off Optimization Under Constraint Duration and Cost of Construction Project</b> .....	115
Kamal Sharma, Anurag Soni, and Manoj Kumar Trivedi	
<b>Optimum Design of Pipe Network Using Rao Algorithm</b> .....	127
Priyanshu Jain, Brijkishore, and Ruchi Khare	
<b>Multi-objective Thermal Exchange Optimization for Truss Structure</b> .....	139
Nikunj Mashru, Pinank Patel, Ghanshyam G. Tejani, and Anchit Kaneria	
<b>Shape Optimization of Structures Considering Varying Geometrical and Material Parameters</b> .....	147
Ishan Jha and Krishna K. Pathak	
<b>Multi-objective Optimization of the Concrete Mixture Blended with Mineral Admixture Using Machine Learning and NSGA-II Algorithms</b> .....	165
Rupesh Kumar Tipu, V. R. Panchal, and K. S. Pandya	
<b>Optimum Design of Tapered Laminated Composite Sandwich Beam Using Teaching–Learning-Based Algorithm</b> .....	175
Naresh Jonna and J. Srinivas	
<b>Optimal Weight Design of 3D Truss Tower Structure with SAP-Rao Algorithm</b> .....	185
Tayfun Dede, Maksym Grzywiński, Barbaros Atmaca, and Ravipudi Venkata Rao	
<b>Computation of Post-tensioning Force of Cable-Stayed Bridge with Jaya Algorithm</b> .....	195
Barbaros Atmaca, Rafiullah Ghafoori, Tayfun Dede, and Şevket Ateş	

**Cost and Design Optimization of a 2-Story RC Building** ..... 203  
 Semi Emrah Aslay, Tayfun Dede, and Ravipudi Venkata Rao

**An Efficient QMF Bank Design Using Differential Search Algorithm** ... 211  
 Hitendra Singh, Atul Kumar Dwivedi, and Deepak Nagaria

**Solution of Fuzzy Multi-objective Traveling Salesman Problem  
 by Multi-objective Quasi Oppositional Jaya Algorithm** ..... 219  
 Aaishwarya S. Bajaj and Jayesh M. Dhodiya

**Performance Assessment and Optimization of Tungsten Inert Gas  
 (TIG) Welding Process Parameters Using Taguchi Method and DEA** ... 235  
 Sujan Mondal, Manthan Maiti, Manik Chandra Das, and Bivash Mallick

**Real Power Loss Minimization by Multiple DG Placement  
 in Distribution System Using Teaching and Learning-Based  
 Optimization Method** ..... 247  
 Deena Lodwal Yadav and S. C. Choube

**Prediction of Delamination Parameters in a Vibrating Laminated  
 Composite Plate Affixed with Piezoelectric Sensor Via Cuckoo  
 Search Optimization** ..... 257  
 Subhransu Kumar Panda and J. Srinivas

**Time–Cost Trade-Off Problems with Multi-objective  
 Quasi-Oppositional Teaching Learning-Based Optimization** ..... 269  
 Mohammad Azim Eirgash, Vedat Toğan, and Tayfun Dede

**Material Selection of Steering Rack in ATV Using AHP** ..... 279  
 Anshul Mangla, Nikhil Dev, and Sandeep Grover

**Measuring the Performance of Circular Supply Chain  
 Implementation Using Pythagorean Fuzzy DEMATEL Approach** ..... 287  
 Swapnil Lahane and Ravi Kant

**Comparative Performance of Coal-Fired Power Plants Using  
 Fuzzy AHP and TOPSIS** ..... 305  
 Soumik Das, Manik Chandra Das, and Bivash Mallick

**A Fuzzy Synthetic Evaluation Approach for Condition Rating  
 of RC Bridge Decks** ..... 319  
 Sudha Das Khan, Pijush Topdar, and Alope Kumar Datta

**A Fuzzy AHP and Fuzzy DEMATEL Approach to Identify  
 Barriers of Practical Implementation of HC in FCEC Scheme** ..... 331  
 Biswarup Chakraborty, Ankita Ray, and Sorokhaibam Khaba

**A Pythagorean Fuzzy AHP Approach to Evaluate the Enablers  
 of Healthcare Operations** ..... 347  
 Yash Deshpande, Takshay Sayre, Aditya Deshmukh, Dain Shaji,  
 and Vishal Bhosale

<b>Solution of Transportation Problem Using Interval-Valued Pythagorean Fuzzy Approach</b> .....	359
Vineet Kumar, Anjana Gupta, and H. C. Taneja	
<b>Applying AHP to Smart City Development: Mobility, Healthcare, and Education</b> .....	369
Dušan J. Simjanović, Nenad O. Vesić, Nemanja Zdravković, and Tatjana Šibalija	
<b>Evaluation of Adaptive Neuro-Fuzzy Inference System for Forecasting Soil's Unconfined Compressive Strength</b> .....	377
Himanshu Jangir and S. Rupali	
<b>Crack Detection in a Dual-Disk Rotor-Bearing System Using Neural Network-Based Non-parametric Approach</b> .....	389
Lokanath Barik and J. Srinivas	
<b>Comparative Fault Analysis of Frequency Disturbance Triggered Hybrid Islanding Detection</b> .....	399
M. Krishna Goriparthi and B. Geetha Lakshmi	
<b>A Smart Video Streaming Web Portal</b> .....	411
Anita Mukund Pujar and Pratibha Arvind Domal	
<b>An SDN-Based DDoS Traffic Generation, Collection and Classification Using Machine Learning Techniques</b> .....	421
T. Arvind and K. Radhika	
<b>An Intelligent Garbage Management System: An IoT-Based Application</b> .....	429
K. Mahindra Guptha, S. Radhika, B. Sateesh, M. Pavan Aditya, and J. Sai Lokesh	
<b>Automatic Segmentation of Cell Nuclei Using VGG-Res-U-Net Architecture</b> .....	435
Wangkheirakpam Reema Devi, Sudipta Roy, and Khelchandra Thongam	
<b>Smart Security System for Cash Dispensing Machine with Theft Protection</b> .....	441
A. Subramaniya Siva, N. Vinothini, and V. Pavithra	
<b>Production of Natural Coagulant from Plant Materials and to Evaluate the Efficiency for Water Treatment Along with Its Validation by ANN</b> .....	447
S. Alfina, N. A. Nikhil, V. S. Akhilesh, S. Anandhu, and N. Anu	
<b>Analysing Failure Prediction for a Manufacturing Firm Using Machine Learning Algorithms</b> .....	457
Aditya Kaushik and Devendra K. Yadav	

**A Deep Learning-Based Approach for Channel Estimation and Equalization for Cognitive Radio Systems** ..... 465  
 Rinkita Shah and Bhagwat Kakde

**A Belief-Degree-Based Environment for Multi-objective Capacitated Transportation Problem** ..... 481  
 Vandana Y. Kakran and Jayesh M. Dhodiya

**Optimisation of Ball Burnishing Parameters for Surface Finish in AL6082** ..... 491  
 Ashish Bahendwar and Achal Shahare

**Real-Coded Genetic Algorithm for Fixed Structure PID Controller Tuning in Sodium Chlorate Process** ..... 499  
 S. Sreepriya, Aparna Kallingal, and M. L. Vinila

**Application of MCDM Approach for Vendor Selection in LED Light Industry** ..... 515  
 Turja Biswaghri and Sourav Das

**Optimum Design of Cumene Reactor Using COMSOL Multiphysics Modelling** ..... 523  
 Vinila Mundakkal Lakshmanan, Aparna Kallingal, and Sreepriya Sreekumar

**Simulation Studies on Optimizing the Substrate Temperature Using a Novel Spiral Filament in Hot Filament Chemical Vapor Deposition of Diamond Thin Films** ..... 533  
 Radhika Panickar, C. B. Sobhan, and Sivaji Chakravorti

**Effect of Runner Hub Cone Geometry on Performance of Kaplan Turbine Using CFD** ..... 547  
 Brijkishore, Priyanshu Jain, Ruchi Khare, and Vishnu Prasad

**Temperature and Thermal Stress Analysis of TBC Coated Diesel Engine Piston for Variable Thickness of TBC** ..... 557  
 Sanket Shejwal and M. R. Ramesh

**Fault Diagnosis of Centrifugal Pump Using Parameter Estimation and Parity Equation** ..... 567  
 Rashi Verma, Raju Yellora, Teja Reddy Vakamalla, and Chandra Shekar Besta

**Algorithm for Extraction of Time-Domain and Linear Features of FHRV** ..... 581  
 Ushasri Akkanapalli, Malini Mudigonda, Sai Sreeja Samavedam, and Meghana Koppadi

**Optimal Auto-Tuned PID Controller for Twin Rotor MIMO System** .... 591  
 Sayani Sengupta and Chanchal Dey

<b>Optimization of Surface Roughness in Wire Cut Electric Discharge Machining of Ti6Al4V Alloy Using Taguchi Method and ANOVA</b> .....	603
Vaishal J. Banker, Ayanesh Y. Joshi, and Sankalp B. Bhatiya	
<b>Multi-objective Design Optimization of Spherical Rolling Bearings</b> .....	611
Ravipudi Venkata Rao and Rahul Baban Pawar	
<b>An Intelligent Cooling System Based on Predictive Time Domain Algorithm with Thermoelectric Coolers for Wind Turbines</b> .....	631
Vigneshwaran Perumal, S. Bakthavatsalam, and B. Saravanan	
<b>Lambda Iteration Technique for Economic Load Dispatch Problem</b> ....	637
Vikas Nishad and Omveer Singh	
<b>Influence of TAKT Time on Optimization of Cost of Production Through Fixation of Workstations</b> .....	647
Biswanath Chakraborty and Santanu Das	
<b>Performance of Multi-criteria Inventory Control Strategies for a Pump Manufacturing Organization</b> .....	661
Ankur Das and Santanu Das	
<b>Trajectory Optimization of an Industrial Robot Using Teaching-Learning-Based Optimization</b> .....	677
V. B. Shinde and P. J. Pawar	
<b>Design of Mechanical Components Using Variants of Rao Algorithm</b> ...	687
R. V. Rao and R. B. Pawar	
<b>Multi-Objective Design Optimization of Solar Dish Stirling Heat Engine</b> .....	701
Ravipudi Venkata Rao and Swapnil Suhas Ranade	
<b>Multi-objective Design Optimization of Plate-Fin Heat Exchanger Using SAMP Rao-3 Algorithm</b> .....	713
Ravipudi Venkata Rao and Majethia Meet Satish	

# About the Editors

**Ravipudi Venkata Rao** is a Professor (Higher Administrative Grade) at the Department of Mechanical Engineering, S. V. National Institute of Technology, Surat, India. He has more than 31 years of teaching and research experience. He completed his B.Tech. in 1988, M.Tech. in 1991, and Ph.D. in 2002, and obtained his D.Sc. in 2017. His research interests include advanced optimization algorithms and their applications to design, thermal and manufacturing engineering, fuzzy multiple attribute decision-making (MADM) methods, and their industrial applications. He has eight authored books and over 350 research papers to his credit, published in national and international journals and conference proceedings. He has received national and international awards for his research efforts. He is a reviewer for over 80 national and international journals and serves on the editorial boards of several international journals. He has also been Visiting Professor at the Cracow University of Technology, Poland; BITS Pilani Dubai Campus; and Asian Institute of Technology, Bangkok.

**Jan Taler** is a Senior Professor in the Department of Energy of the Faculty of Environmental and Energy Engineering of Cracow University of Technology, Poland. He has more than 45 years of teaching and research experience, having completed his M.Sc. in 1974, Ph.D. in 1977, and D.Sc. in 1987. He has published more than 380 articles in scientific journals. He has authored 12 books and over 25 chapters in scientific monographs and entries in the Encyclopedia of Thermal Stresses. He researches in the field of heat transfer engineering and thermal power engineering with a special interest in the following areas—inverse heat conduction problems, measurement of heat flux and heat transfer coefficient, ash fouling and slagging in steam boilers, dynamics of large steam boilers, and optimization of thermal systems. He has participated in many research projects funded by industry and the Polish Committee for Scientific Research. Many of his innovative technical solutions have been implemented in power plants.

# Process Parameters Optimization by Taguchi Method and Whale Optimization Algorithm of Lathe Turning on EN24 Steel for Prediction of Surface Roughness



Abhishek Sakat, Amit Sonar, Sanket Ghodake, Rohit Mule, Atul Kulkarni, Prashant Anerao, and Shailendra Ambatkar

## 1 Introduction

EN24 steel is a common steel used in industry. A large number of studies have been conducted to determine the optimal machining settings for EN24 steel [1]. Taguchi and Konishi devised the Taguchi technique, which is a statistical method. It was originally created to improve the quality of produced items, but it has since been applied to a wide range of engineering sectors, including biotechnology and others. The Taguchi method entails identifying appropriate control parameters in order to get the best possible process results. A set of tests is carried out using orthogonal arrays (OA). The data from these experiments is analysed, and the quality of the components created is predicted. For further optimization of the parameters, metaheuristic algorithm like the whale optimization algorithm is used.

## 2 Process

The machining of EN24 is carried out on an ACE Micromatic CNC machine with a PCLNL tool holder, and a HSS tool is used. The other end of material is centre-bored using centre drill. After that, according to the design of experiment different levels of parameters are set to get numbers of run. The workpiece was given initial roughness pass. Statistical analysis of obtained data was carried out using Taguchi optimization

---

A. Sakat (✉) · A. Sonar · S. Ghodake · R. Mule · A. Kulkarni · P. Anerao  
Vishwakarma Institute of Information Technology, Pune, Maharashtra 411048, India  
e-mail: [abhishek.22020126@viit.ac.in](mailto:abhishek.22020126@viit.ac.in)

S. Ambatkar  
D. Y. Patil Educational Complex, Pune, Maharashtra 411044, India

© The Author(s), under exclusive license to Springer Nature Singapore Pte Ltd. 2023  
R. Venkata Rao and J. Taler (eds.), *Advanced Engineering Optimization Through Intelligent Techniques*, Lecture Notes in Mechanical Engineering,  
[https://doi.org/10.1007/978-981-19-9285-8\\_1](https://doi.org/10.1007/978-981-19-9285-8_1)

technique. A Surftest Mitutoyo SJ-201 Series 178-Portable Surface Roughness Tester is used to get the response variable, i.e. the surface roughness.

## 2.1 Identify the Control Factors and Their Levels

Experiments were designed using Taguchi method which uses an OA to study the entire parametric space with a limited number of experiments. In the present research, two parameters (factors) were chosen such as speed and depth of cut. All of them were set at three different levels. Spindle speed at 200, 350 and 500 rpm, feed at 0.5, 1, 15 mm/rev and depth of cut at 1, 1.5, 2 mm, respectively.

## 2.2 Conducting the Experiment

According to Taguchi's orthogonal array theory L9 orthogonal array is adopted for the whole experimentation for turning operation of mild steel. In accordance with above OA, experiments were conducted with their factors and their level as mentioned in Table 2. The surface roughness was measured using the surface roughness tester. Table 3 shows the measured values of surface roughness obtained from different experiments.

**Table 1** L9 array with values of response variables

Sr. no	Spindle speed (RPM)	Feed rate (mm/min)	Depth of cut (mm)	Surface roughness Ra ( $\mu\text{m}$ )
1	200	0.5	1.0	2.51
2	200	1.0	1.5	7.12
3	200	1.5	2.0	12.92
4	350	0.5	1.5	2.53
5	350	1.0	2.0	4.98
6	350	1.5	1.0	6.27
7	500	0.5	2.0	1.87
8	500	1.0	1.0	2.62
9	500	1.5	1.5	5.24

**Table 2** Current best solution

Sr. No	Spindle speed (RPM)	Feed rate (mm/min)	Depth of cut (mm)
7	500	0.5	2.0

**Table 3** Results from S/N ratios and WOA

Parameter	Results from S/N ratio	Results from WOA
Spindle speed	500	500
Feed rate	0.5	0.5
Depth of cut	1	1
Surface roughness	1.50256	1.3396

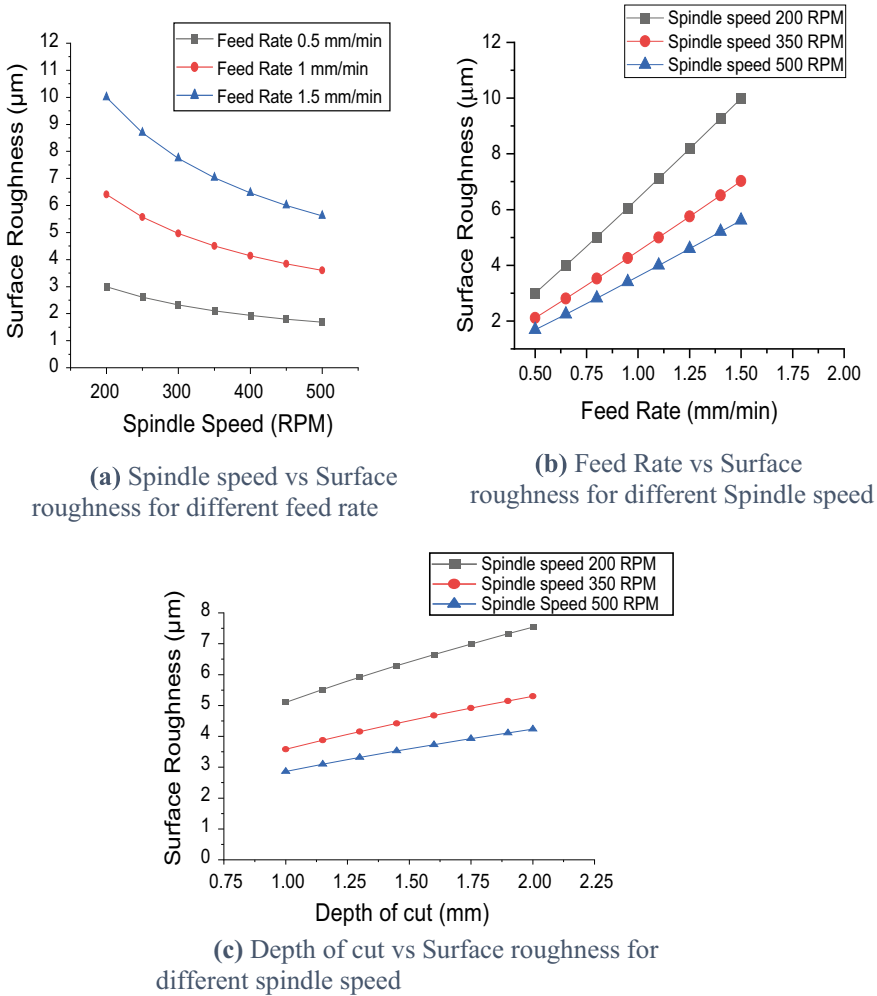
Figure 1a–c shows the effect of the cutting parameters on the surface roughness. From Fig. 1a, we can infer that as the spindle speed increases the surface roughness decreases. This is inverse in the case of feed rate as shown in Fig. 1b and depth of cut as shown in Fig. 1c, whereas the feed rate and depth of cut increase the surface roughness also increases. But in case of feed rate, the slope of the curve is more so we can infer that feed rate increases the surface roughness more as compared to the depth of cut.

### 3 The Whale Optimization Algorithm

#### 3.1 *Hunting Technique of Humpback Whales*

Whales are magnificent creatures. Whales are among the world’s largest mammals. An adult whale can reach a length of 30 m and a weight of 180 tonnes. Killer whales, Minke whales, Sei whales, humpback whales, right whales, finback whales and blue whales are among the seven primary species of this enormous mammal. Whales are mostly considered predators. Whales are considered highly intelligent animals with emotion [1–7].

Humpback whales have a unique hunting technique due to their size and weight. This hunting technique is called as bubble-net feeding method. The bubble-net feeding method is a cooperative feeding method used by groups of Humpback whales. As whales are known to communicate with each other through vocalization, they also share and coordinate in this manoeuvre and efficiently execute the bubble-net so they can all feed. During the feeding process, the group circles a school of small fish and they use a team effort to disorient the fish into a ‘net’ of bubbles. The whales will typically begin to exhale out of their blowholes at the school of fish, creating a large net of bubbles. While blowing the bubbles, the whale will also continue to encircle the prey. One whale will sound the feeding call, at which point all whales simultaneously start swimming upwards with mouths wide open to feed on the trapped fish.



**Fig. 1** **a** Spindle speed versus surface roughness for different feed rate. **b** Feed rate versus surface roughness for different spindle speed. **c** Depth of cut versus surface roughness for different spindle speed

### 3.2 Whale Optimization Algorithm

The bubble-net feeding technique of humpback whales can be idealized, and an algorithm can be developed using this technique [1]. Mirjalili and Lewis developed this whale inspired algorithm in their paper titled ‘The Whale Optimization Algorithm’.

The whale optimization algorithm (WOA) incorporates a mathematical model of encircling prey, spiral bubble-net feeding manoeuvre and search for prey for optimization [1]. Mirjalili and Lewis explored these behaviour  $\vec{A} = 2 \cdot \vec{a} \cdot \vec{r} - \vec{a}$  of

humpback whales and developed the WOA. The WOA consists of the following sections.

1. Encircling Prey
2. Bubble Net Hunting Method
3. Search the prey

### Encircling Prey

The WOA assumes that the current-based solution obtained by different DOE or other techniques is the best target prey. The search agents try to update their positions towards the best search agent. The following equations represent the behaviour.

$$\vec{D} = \left| \vec{C} \cdot \vec{X}(t) - \vec{X}(t) \right| \quad (1)$$

$$\vec{X}(t+1) = \vec{X} * (t) - \vec{A} \cdot \vec{D} \quad (2)$$

$$\vec{A} = 2\vec{a} \cdot \vec{r} - \vec{a} \quad (3)$$

$$\vec{C} = 2 \cdot \vec{r} \quad (4)$$

where  $t$  is the current iteration and  $X^*$  is the position of the best solution, and it is updated if better solution is obtained,  $\vec{X}$  is the position vector.  $\vec{A}$  and  $\vec{C}$  are the coefficient vectors, where  $\vec{a}$  is linearly decreased from 2 to 0 and  $\vec{r}$  is a random vector [0,1].

### Bubble net feeding method (exploitation method)

This section consists of two approaches.

#### *Shrinking encircling prey*

This mechanism is achieved by decreasing the value of  $\vec{a}$  in Eq. (3). Figure shows the possible positions from  $(X, Y)$  towards  $(X^*, Y^*)$  that can be achieved by  $0 \leq A \leq 1$  in 2D space in Eq. (3).

#### *Spiral Position Update*

To mimic the helically shaped movement, a spiral equation is used between the position of whales and prey.

$$\vec{X}(t+1) = \vec{D}' \cdot e^{bl} \cdot \cos(2\pi l) + \vec{X} * (t) \quad (5)$$

where  $\vec{D}' = \left| \vec{X} * (t) - \vec{X}(t) \right|$  and it indicates the distance between the whale and the prey,  $b$  is a constant,  $l$  is a random number in between  $[-1,1]$ .

During hunting, the whales use both shrinking encircling and spiral-shaped path simultaneously. To incorporate this simultaneous movement, we assume a probability

of 50% between shrinking encircling and spiral-shaped path to update the position of whales.

$$\vec{X}(t+1) = \begin{cases} \vec{X}^*(t) - \vec{A} \cdot \vec{D} & \text{if } p < 0.5 \\ \vec{D} \cdot e^{bl} \cdot \cos(2\pi l) + \vec{X}^*(t) & \text{if } p \geq 0.5 \end{cases} \quad (6)$$

where  $p$  is a random number in between  $[0,1]$ .

### Search for prey (Exploration phase)

In order to make the algorithm global parameter optimizer when greater than 1 or less than 1 the search agent is updating accordingly to a randomly chosen agent instead of the best search agent (Figs. 2, 3 and 4).

$$\vec{D} = \left| \vec{C} \cdot \vec{X}_{\text{rand}} - \vec{X} \right| \quad (7)$$

$$\vec{X}(t+1) = \vec{X}_{\text{rand}} - \vec{A} \cdot \vec{D} \quad (8)$$

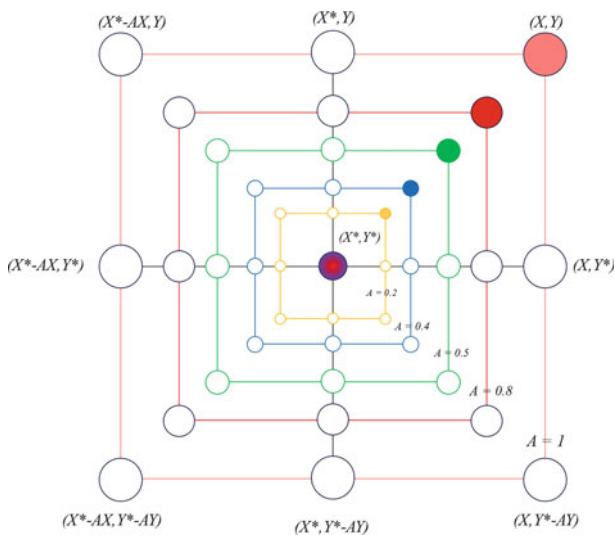


Fig. 2 Shrinking encircling prey mechanism

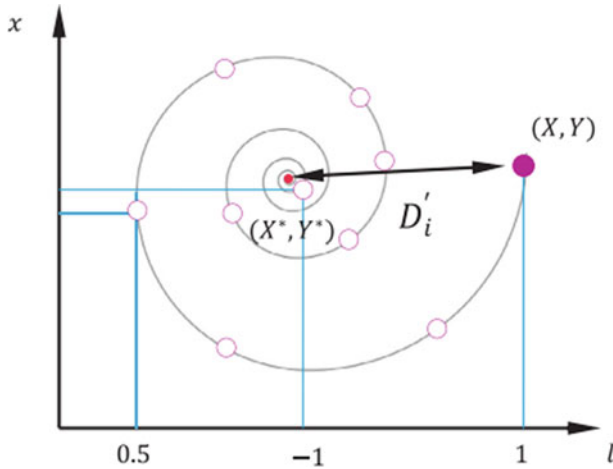


Fig. 3 Spiral feeding mechanism

```

Initialize the whales population  $X_i (i = 1, 2, \dots, n)$ 
Calculate the fitness of each search agent
 $X^*$ =the best search agent
while ( $t <$  maximum number of iterations)
  for each search agent
    Update  $a, A, C, l,$  and  $p$ 
    if1 ( $p < 0.5$ )
      if2 ( $|A| < 1$ )
        Update the position of the current search agent by the Eq. (2.1)
      else if2 ( $|A|$ )
        Select a random search agent ( $r$ )
        Update the position of the current search agent by the Eq. (2.8)
      end if2
    else if1 ( $p > 0.5$ )
      Update the position of the current search by the Eq. (2.5)
    end if1
  end for
  Check if any search agent goes beyond the search space and amend it
  Calculate the fitness of each search agent
  Update  $X^*$  if there is a better solution
   $t=t+1$ 
end while
return  $X^*$ 
  
```

Fig. 4 Pseudo-code for whale optimization algorithm

## 4 Results Analysis and Discussion

### 4.1 Current Best Solution Obtained from Taguchi

It is observed from Table 3 that Spindle speed of 200 rpm, feed rate of 1.5 mm/min and depth of cut 2 mm gives the lowest surface roughness which is desired (lower is better) i.e. the values of parameters corresponding to Sr. no. 3, gave best solution. This solution obtained from Taguchi optimization will be our current best solution in the whale optimization algorithm.

### 4.2 Regression Analysis

Regression analysis was used to predict the link between the factors of Spindle speed, depth of cut and feed, as well as the performance measurement surface roughness. The final regression model in terms of the encoding parameters of the following parameters is denoted:

$$\text{Surface Roughness} = 143.485 * \text{Spindle Speed}^{(-0.6298)} \\ * \text{Feed}^{(1.096)} * \text{DOC}^{0.5637}$$

The above regression equation is made by using some empirical relations and by using the power law. For this purpose, the DataFit 9.0 software is used.

### 4.3 Results and Discussion

The regression equation obtained after applying Taguchi is given as an input to the WOA for further optimization. The whale optimization algorithm code was run on MATLAB® 2021. The results obtained from WOA are compared to results from S/N ratio. The graph representing the optimization obtained from the whale optimization algorithm is shown in Fig. 5

## 5 Conclusion

From this study, it has been observed that the whale optimization algorithm can be effectively applied to optimization problems. The results obtained from S/N ratio and WOA are quite similar with some difference, due to the use of linear regression curve fitting model for regression analysis. The Taguchi method coupled with metaheuristic

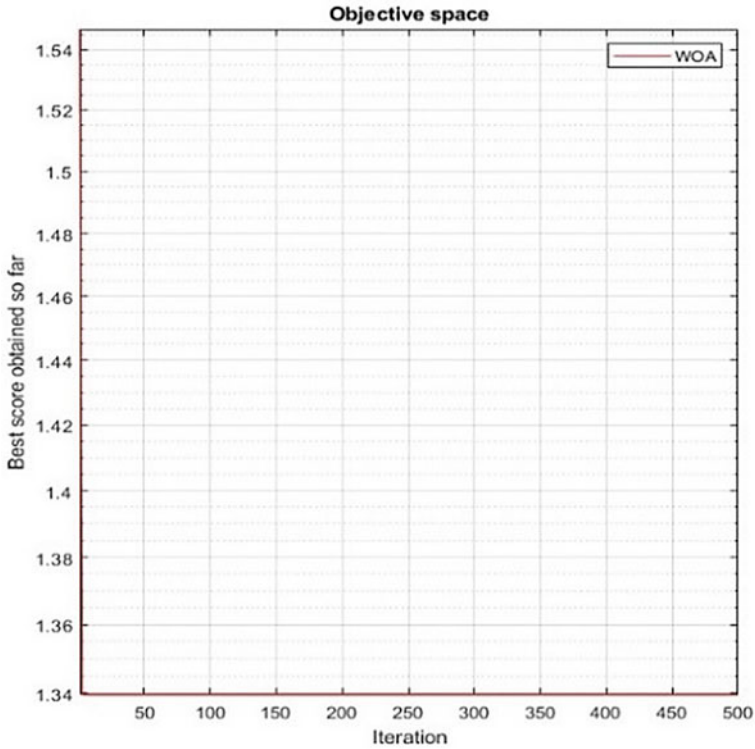


Fig. 5 Optimal answer obtained from WOA

optimization algorithms can be used in the design of experiments and parametric optimization as well.

## References

1. Mirjalili S, Lewis A (2016) The whale optimization algorithm. *Adv Eng Softw* 95:51–67. <https://doi.org/10.1016/j.advengsoft.2016.01.008>
2. Singh H, Kumar P (2006) Optimizing feed force for turned parts through the Taguchi technique. *Sadhana* 31(6):671–681
3. Ahmed SG (2006) Development of a prediction model for surface roughness in finish turning of aluminium. *Sudan Eng Soc J* 52(45):1–5
4. Mahmoud EAE, Abdelkarim HA (2006) Optimum cutting eters in turning operations using HSS cutting tool with 450 approach angle. *Sudan Eng Soc J* 53(48):25–30
5. Yadav A, Bangar A, Sharma R, Pal D (2012) Optimization of turning process parameters for their effect on En 8 material work piece hardness by using taguchi parametric optimization method. *Int J Mech Ind Eng (IJMIE)* 1(3)
6. Ranganath M, Vipin S (2013) Optimization of process parameters in turning operation using Taguchi method and Anova: a review. *Int J Adv Res Innov* 1(2013):31–457

7. Wagh SS, Kulkarni AP, Sargade VG (2013) Machinability studies of austenitic stainless steel (AISI 304) using PVD cathodic arc evaporation (CAE) system deposited AlCrN/TiAlN coated carbide inserts. Proc Eng 64:907–914. <https://doi.org/10.1016/j.proeng.2013.09.167>. ISSN 1877-7058

# Optimization of TWR and SR of Superalloy Al/9.6B4C in EDM Using Advanced Optimization Techniques



Neeraj Agarwal and M. R. Singh

## 1 Introduction

Superalloys are prevalent engineering materials nowadays. They have excellent engineering properties. Al/B4C is a perfect substance that is commonly used in the aircraft and automotive industries. This is very hard material, and hence machining is difficult by traditional machining due to its low weight and improved wear characteristics. For the shaping of these superalloys, non-traditional processing methods are commonly used. Unconventional machining like EDM is used to machine the superalloy. Due to sparking between the workpiece and electrode, there is a sudden rise in temperature in the machining zone. Due to this high temperature, the material is removed by melting and evaporation in a small amount [1]. There are many control parameters used for the EDM process like Ton, Toff, current ( $I$ ), duty factor ( $t$ ). The TWR and surface SR are considered as process outcome. Dubey and Singh [2] mixed chromium particles in the dielectric to enhance the MRR and surface integrity. Further, Huu et al. [3] used the response surface method to analyze and plan the experiments. Saad et al. [4] conducted an investigation with Al–Si alloy and studied parameters of EDM on RSM-based, combined with desirability function (DF); they developed RSM for Toff, Ton, pulse current and their effect on the MRR, TWR as well as SR. Further, it has been concluded that RSM was sufficient for predicting the EDM method behaviors properly. Equbal et al. [5] have been reported die-sinking EDM of stainless steel through copper electrode; kerosene is selected as dielectric fluid. Current, Ton, and spark off time are the chosen process performance parameters for machining. The

---

N. Agarwal (✉)

Department of Mechanical Engineering, IES College of Technology, Bhopal,  
Madhya Pradesh, India

e-mail: [neeraj.bhopal@gmail.com](mailto:neeraj.bhopal@gmail.com)

M. R. Singh

Department of Mechanical Engineering, SRIT, Jabalpur, Madhya Pradesh 483001, India

output measure is MRR, and RSM is selected to quantify the effect of several parameters on the MRR. Sahu et al. [6] designed using RSM and conducted two sets of experiments by the different dielectric. Yadav and Yadava [7] used abrasion-based compound wheel for SiC-B4 MMC machining. Peak current, Ton, Toff, WS, and abrasive grit size were input parameters for evaluating MRR and surface quality. However, Kandpal et al. [8] used EDM to machine Al–Al<sub>2</sub>O<sub>3</sub>. They have been found the optimum values of control parameters by using Taguchi techniques to maximize the MRR. Kumar and Prakash [9] used EDM of aluminum-B4C MMC to calculate the effects of Ton, current, Toff, and electrode material on SR, TWR, and MRR.

Pramanik and Basak [10] investigate the effect of wire tension, dielectric flushing pressure and Ton on wire rupture during EDM of Ti/6Al/4V. Abidi et al. [11] find the best machining parameters for a higher MRR and a good surface finish. They show that multiobjective genetic algorithm (MOGA-II) is an effective method for optimizing input parameters. Dwaipayana et al. [12] machined pure sintered titanium on EDM. They used RSM for the design of experiments. They optimize the Ton, Toff, wire tension to minimization of kerf width and over cut. Arikatla et al. [13] investigate various input EDM settings on kerf width, MRR, surface roughness, and surface topography of wire EDM for the titanium alloy workpieces. Baroi et al. [14] used Taguchi-based DOE for Titanium Grade 2 alloy and find optimum parameter for MRR, TWR, and SR. Rajesh et al. [15] investigate the impact of various input control parameters like ‘Ton’, ‘Toff’, ‘I’ on MRR and SR on EDM for the AISI1020 steel. In this, ANN methods were applied to predict the optimized parameters. They concluded that on these models, an advanced technique output with a kind of empirical model provided excellent results on comparing with the RSM model in terms of tolerable error. Singh and Shrivatava [16, 17] also created an AIB4C metal matrix composite with an appropriate composition and discovered that EDM is a viable machining method. They came to the conclusion that the modeling and optimization techniques RSM, GA, and JAYA algorithm outperform the others. For AISI D2 steel machining, Agarwal et al. employed a new Jaya method to optimize four input variables [18]. For multiobjective optimization of the titanium alloy, Agarwal et al. applied advanced optimization techniques for relative tool wear rate optimization [19]. Rao et al. applied Jaya algorithm in surface grinding optimization [20]. Singh et al. [21] contrasted the optimal method and used EPSDE techniques on AMMCs, which produced better results.

Many researchers work on machining of AMMCs, but there is no EDM work reported on ALB4C. ALB4C has an excellent alternative for various parts of the automobile and aviation industry due to its higher wear resistance properties. Rao-1 is a new optimization technique developed by Rao [22] for engineering optimization. In this research, Rao-1 optimization is used for the optimization of machining parameters. Very little work is reported on this algorithm.

## 2 Methodology

### 2.1 Response Surface Model (RSM)

In RSM, the following expression is used;

$$y = f(x_1, x_2, x_3, \dots, x_p), \quad (1)$$

where  $y$  = response,  $x_1, x_2, x_3, \dots, x_n$ , = process control variables. RSM establishes a second-order regression model between the response and process control variables as follows [17].

$$y = b_o + \sum_{i=1}^p b_i x_i + \sum_{i=1}^p b_{ii} x_i^2 + \sum_i \sum_j b_{ij} x_i x_j \quad (2)$$

where all  $b_s$  are constant and coefficients for the RSM model.

## 3 Experimental Setup

### 3.1 CNC Electronic EDM Machine

Figure 1 shows the EDM used to execute the experiment. The ‘ $T$ ’, ‘Ton’, and ‘Toff’ were chosen as input control parameters. The control parameters are depicted in Table 1 together with their levels. The DOE is based on the Box–Behnken design. The Al-9.6B4C is used as a workpiece. As a tool electrode, the copper rod is employed. Each experiment was conducted for 30 min with straight polarity. TWR is evaluated for each experiment using Eq. (4). The electronic weighing balance has a 0.1 mg resolution. Surface roughness is measured using Mitutoyo Surtronic SJ-201P surface profilometer.

The TWR unit in mg/min has been measured according to the following relationship:

$$\text{tool wear} = m_i - m_f \quad (3)$$

$$\text{TWR} = \frac{m_i - m_f}{t_p} \quad (4)$$



**Fig. 1** EDM setup

**Table 1** Input control parameters and levels

Parameters/level	Variable	Level 1 (-1)	Level 2 (0)	Level 3 (1)
Peak current (A)	X1	1	3	5
Pulse-on time ( $\mu$ s)	X2	10	20	30
Pulse-off time ( $\mu$ s)	X3	15	20	25

where  $m_i$  and  $m_f$  are initial and final weights of the tool after machining. Table 2 shows the two responses, TWR and SR.

## 4 Modeling and Optimization

### 4.1 Response Surface Model (RSM)

#### 4.1.1 Regression Model for TWR

MATLAB 11 was used to generate the second-order RSM modeling of TWR. Equation (5) depicts the TWR regression model. All non-significant terms are removed. The values of the  $R^2$  and modified  $R^2$  decision coefficients are 0.9503 and 0.9227, respectively. This demonstrates the model's significance.

The regression model for TWR is given below,