Lecture Notes in Mechanical Engineering

M. S. Shunmugam
Biswanath Doloi
R. Ramesh
A. S. Prasanth *Editors*

Advances in Modern Machining Processes

Proceedings of AIMTDR 2021

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

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
China: Ella Zhang at ella.zhang@springer.com
India: Priya Vyas at priya.vyas@springer.com
Rest of Asia, Australia, New Zealand: Swati Meherishi at swati.meherishi@springer.com
Topics in the series include:

- Engineering Design
- Mechanical Structures and Stress Analysis
- Engine Technology
- Nanotechnology and Microengineering
- Control, Robotics, Mechatronics
- MEMS
- Theoretical and Applied Mechanics
- Fluid Mechanics
- Engineering Thermodynamics, Heat and Mass Transfer
- Manufacturing
- Precision Engineering, Instrumentation, Measurement
- Tribology and Surface Technology

Indexed by SCOPUS and EI Compendex**.** 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

M. S. Shunmugam · Biswanath Doloi · R. Ramesh ·
A. S. Prasanth
Editors

Advances in Modern Machining Processes

Proceedings of AIMTDR 2021

Springer

Editors
M. S. Shunmugam
Department of Mechanical Engineering
Indian Institute of Technology Madras
Chennai, India

Biswanath Doloi
Production Engineering
Jadavpur University
Kolkata, India

R. Ramesh
Department of Mechanical Engineering
PSG Institute of Technology and Applied Research
Coimbatore, India

A. S. Prasanth
Department of Mechanical Engineering
PSG College of Technology
Coimbatore, India

ISSN 2195-4356 ISSN 2195-4364 (electronic)
Lecture Notes in Mechanical Engineering
ISBN 978-981-19-7149-5 ISBN 978-981-19-7150-1 (eBook)
https://doi.org/10.1007/978-981-19-7150-1

© 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

Preface

All India Manufacturing Technology, Design and Research (AIMTDR) is a reputed international conference series focused on the domain of manufacturing. The first All India Machine Tool Design and Research conference, also abbreviated as AIMTDR, was organized by Jadavpur University, Kolkata, in the year 1967. Those were the days when the main focus of manufacturing was toward efficient design and utilization of machine tools. PSG College of Technology, Coimbatore, organized the 7th and 15th AIMTDR conferences in 1976 and 1992, respectively. Other institutes that organized this conference before the 15th AIMTDR conference are Central Machine Tool Institute (CMTI), Indian Institute of Technology (IIT) Bombay, IIT Madras, University of Roorkee, IIT Kanpur, Central Mechanical Engineering Research Institute and IIT Delhi, some of them multiple times. After the 15th AIMTDR conference, the necessity of widening the scope of the conference arose. It was decided to encompass entire manufacturing technologies in its fold, rather than just focusing on the technologies related to machine tools. Accordingly, the phrase "machine tool design" was replaced by "manufacturing technology, design". Thus, the conference series was rechristened as All India Manufacturing Technology, Design and Research, without making any alteration to the acronym AIMTDR. Thus, the 16th AIMTDR conference with a new unabridged title was organized at CMTI, Bangalore, in 1994. It is interesting to note that CMTI renamed itself from Central Machine Tool Institute to Central Manufacturing Technology Institute in 1992, adapting to the current trends in manufacturing.

AIMTDR received its international status in the year 2006, when the first International and 22nd National AIMTDR was organized at IIT Roorkee. Subsequent conferences were held at IIT Madras, Andhra University, Jadavpur University, IIT Guwahati, College of Engineering Pune and Anna University. The recent edition of the conference, viz., the 8th international and 29th national conference, was jointly organized by the Departments of Mechanical Engineering of PSG College of Technology, Coimbatore, and PSG Institute of Technology and Applied Research, Coimbatore, during 9–11 December 2021 in virtual mode. The theme of AIMTDR 2021 was "*Transformational Changes in Manufacturing*".

After a rigorous review process, about 250 technical papers from academia and industry were accepted for presentation at the conference. In addition, eight keynote talks on advanced technologies such as the development of high-precision machine tools, simulation of material flow, nanostructured surfaces, additively controlled material mechanics, product development platforms, next-generation milling, diamond turning and hybrid machining were delivered by experts. Further, two case studies from the industry highlighting the innovation practices and challenges in machine tool structure design were presented.

Select papers from the conference are being published by Springer in the series—*Lecture Notes in Mechanical Engineering*, in five volumes—Volume 1: Advances in Modern Machining Processes; Volume 2: Advances in Additive Manufacturing and Metal Joining; Volume 3: Advances in Simulation, Product Design and Development; Volume 4: Advances in Forming, Machining and Automation; Volume 5: Advances in Micro and Nano Manufacturing and Surface Engineering.

Volume 1 entitled "Advances in Modern Machining Processes" covers neoteric advances in the realms of Electro-Physical and Chemical Machining, Machining Optimization, Surface Morphology and Sustainable Machining. We hope that this book will evoke interest among academicians, researchers and practicing engineers who aspire to comprehend advances pertaining to the domain of modern machining processes.

We sincerely thank National Advisory Committee members of AIMTDR, organizers, reviewers, authors and participants. Special thanks to Springer for publishing the select papers of AIMTDR since AIMTDR 2014. Readers are requested to send us their feedback about this volume.

Chennai, India M. S. Shunmugam
Kolkata, India Biswanath Doloi
Coimbatore, India R. Ramesh
Coimbatore, India A. S. Prasanth

Contents

About the Editors

Dr. M. S. Shunmugam was Professor (Emeritus) in the Manufacturing Engineering Section in the department of mechanical engineering, Indian Institute of Technology (IIT) Madras. After receiving his Ph.D. in Mechanical Engineering from IIT Madras in 1976, he served in IIT Bombay (from 1977 to 1980) and in IIT Madras from 1980 onwards. He was a visiting faculty member at Michigan Technological University during 1989–1991 and was a member of the Board of governors of IIT Madras during 2012–2013. Dr. Shanmugam's research interests include metrology, machine tools, manufacturing, gears, micro-machining and computer applications in manufacturing. He has published about 130 peer-reviewed international journal papers, 15 peer-reviewed national journal papers, 75 international conference papers and about 80 national conference papers.

Dr. Biswanath Doloi is currently serving as Professor in the department of production engineering at Jadavpur University, India. He has over two decades of teaching and research experience. Dr. Doloi's research is focused on non-traditional machining, hybrid machining, micromachining, and laser-based manufacturing. He has written several book chapters and published articles in acclaimed international journals. He has guided 19 research scholars and is a member of IE (India), ISTE and IET, UK.

Dr. R. Ramesh is Professor in the department of mechanical engineering, PSG Institute of Technology and Applied Research, India. He earned his Ph.D. in Production Engineering from National Institute of Technology Tiruchirappalli, India. An experienced academician with over 20 years of teaching experience, he has published over 20 research articles in conferences and reputed international journals which have cumulatively received in excess of 200 citations. His research interests are geometric dimensioning, tolerance analysis, tolerance allocation, composites manufacturing and optimization techniques. Dr. Ramesh is pursuing a research project on co-continuous composites for ballistic applications in collaboration with UNSW, Canberra, Australia. This project is sponsored by SPARC, MHRD, Government of India. He is also a life member of ISTE, New Delhi.

Dr. A. S. Prasanth is Assistant Professor in the department of mechanical engineering, PSG College of Technology, India. He received his Master's in Industrial Engineering from Wayne State University, USA and Ph.D. from Anna University, India. He has published about 20 research articles spanning the domains of industrial engineering, fabrication of composites, frictional behavior and 3D printing. He is a recognized Chartered Engineer by the Institution of Engineers (India).

Electro-Physical and Chemical Machining

A Sustainable Die-Sinking Electrical Discharge Machining of Ti6Al4V Using Jatropha Bio-Dielectric

Shirsendu Das, Swarup Paul, and Biswanath Doloi

Abstract The feasibility of jatropha bio-oil is already judged technically as a green and sustainable dielectric of EDM in terms of material removal, surface roughness and surface hardness. However, it cannot be appreciated as a reliable alternative to conventional paraffin oils. The present study is an attempt to identify some of those hurdles for which jatropha can't be prioritized for industrial practices. Here, the performances of jatropha and kerosene are experimented with under various ranges of flushing conditions, and their impacts on morphological features have been examined. It is observed that jatropha can offer 20% more MRR and 10% less roughness than kerosene, but causes more thermal defects. Therefore, a suitable range of flushing pressure and velocity have been recommended to ensure desirable surface characteristics and responses with jatropha, so that the issues of sustainability can be entertained.

Keywords EDM · Green dielectric · Jatropha · Roughness · Morphology · Crack · Defects

1 Introduction

Electro-discharge machining is one of the commonly used unconventional approaches which has huge utilities in industrial domains. The easy availability and low cost make kerosene a reliable medium for industrial purposes, but it causes toxic evolvements, which is unhygienic for the operators [1–3]. Moreover, the lengthy removal process requires more time and power than conventional processes [4] and the biodegradability of the developed waste is a challenging issue in the present socio-economic context [5, 6]. In this aspect, the ISO14000 mandate can be adopted to entertain the sustainability issues of manufacturing processes, including the safety

S. Das (✉) · S. Paul
Production Engineering Department, National Institute of technology, Agartala, Tripura, India
e-mail: shirsendu1989@gmail.com

B. Doloi
Production Engineering Department, Javadpur University, Kolkata, West Bengal, India

© The Author(s), under exclusive license to Springer Nature Singapore Pte Ltd. 2023
M. S. Shanmugam et al. (eds.), *Advances in Modern Machining Processes*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-19-7150-1_1

and health issues of the operators along with cost, energy and material consumption, management of waste and environmental impact [7, 8]. Meanwhile because of higher breakdown capacity, viscosity, nontoxicity and easy degradability, vegetable oils like jatropha, neem, canola, palm, sunflower, etc. can be considered as an alternative as they have already exhibited impressive response experimentally. Valaki et al. [9] observed impressive outcomes with enhanced MRR, less SR and good hardness with jatropha. Moreover, ANOVA analysis was also performed for the assessment of the impacts of process parameters on the obtained responses. Ng et al. [10] compared the performances of canola, sunflower and kerosene and addressed the issues of partial burning and monoxide evolvement along with their inimical impacts on operator's health. Moreover, experimentally, more than 100% MRR was observed with a considerable reduction in tool consumption during the machining of metallic glass and titanium.

Coconut oil, palm oils and waste vegetable oil (WVO) are also recommended as alternative dielectrics in some research. Outcomes claimed that WVO had shown better responses than kerosene. Moreover, the impacts of dielectric physio-chemical properties on EDM responses are also found to be conspicuous here [11]. Similarly, the performances of bio-dielectric blends (BDB) were compared with paraffin oils where BDB ensured a notable contribution in MRR (38 to 138% more) but entertained excess tool consumption (100 to 275% more) than kerosene. The ANOVA analysis claimed that the current has the most impact on responses (MRR and TW) [12].

These are some notable attempts in the domain of green dielectrics to emphasize the sustainability of EDM. However, to date these dielectrics are not accredited as suitable for industrial practices because of their higher viscosity, density and poor flowability. Moreover, no preferable ranges of flushing variables are mentioned for these bio-dielectrics in the available literature. Therefore, this study attempted to evaluate the impacts of flushing pressure and velocity on the responses, especially on surface properties. Experiments have been conducted with both jatropha and kerosene for the same sets of input parameters and flushing conditions, and both the affirmative and adverse impacts on surface properties have been judged, which are discussed here in subsequent stages.

2 Materials and Methods

The responses like SR, MRR and thermal defects have been examined for various flushing ranges. Here, Ti6Al4V alloy and cylindrical copper tool of 10 mm diameter have been chosen to make the observation more industrially viable. Because of its colossally in aerospace industries and bio-medical instrumentation [13–15] and due to its 'hard to machine' behavior 'Ti6Al4V' has apprehended global attention. Literature claimed copper as the best tool to machine 'Ti6Al4V' because it assured less tool consumption with both polarities. However, the reverse polarity is preferred here, as it has been found convenient to machine 'Ti6Al4V' experimentally [16, 17]. The Sparkonix Die-Sinking (EDM) Machine has been used for experimentation which is assisted by a Servomax servo stabilizer. In this approach, the flushing pressure and velocity are also considered as process parameters to make the observation more justified.

Kerosene is used as the conventional dielectrics and the transesterified bio-oil extracted from the seeds of Jatropha curcas is chosen as a green dielectric medium. The chemical properties of both these dielectrics are presented in Table 1. Experiments are conducted with 50 L of dielectrics (each) inside a confined domain of dimension 30 cm × 20 cm ×15 cm. A small pump is used to circulate the dielectrics from the 'dielectric drum' to the machining chamber. Here, a range of 15 kg/cm^2–27 kg/cm^2 flushing pressure and 0.20–0.45 m/s of flushing velocity were used. Finally, the impacts of these process variables on MRR and SR have been observed. The MRR is measured using the weight subtraction method, as followed in Eq. 1:

$$MRR = \frac{W_i - W_f}{\rho t} \times 1000 \tag{1}$$

Here, 'W_i' and 'W_f' are the weights in gram (g), before and after the machining, 'ρ' is the sample density in g/cm^3 and 't' stands for the time (min.). The SR is measured with a Digital profilometer in µm which is presented in Table 2.

Experiments are performed in a confined chamber (30 cm ×20 cm ×15 cm), with 50 L of each dielectric fluid. An extra pump and flushing arrangement are assigned to flush and circulate the dielectrics from the dielectric tank to the chamber. The scanning electron microscope having 10–1,000,000 x (approx.) magnification and 0.02–30 kV range of A.P is preferred to evaluate the final textures of the EDMed surfaces. The used machine (EDM) and SEM are shown in Fig. 1.

Table 1 Specification of the workpiece material [18]

Elements	Ti	Al	V	C	Fe	O	H	N
Composition (%)	89.46	6.92	4.03	0.02	0.21	0.19	0.006	0.03

Table 2 Properties of kerosene and jatropha dielectric [18]

S. no	Properties with units	Kerosene	Jatropha
1	Density (gm/ml)	0.805	0.868
2	Viscosity (cts)	1.21	6.60
3	Thermal Conductivity (W/mK)	0.128	0.146
4	Specific Heat (kJ/kgK)	2.06	1.93
5	Breakdown Voltage (kV)	48	26
6	Dielectric Constant	2.12	3.24
7	Flash Point (^{0}C)	54	171

(a) Sparkonix EDM- Machine (b) Zeiss Scanning Electron Microscope

Fig. 1 Equipment used

3 Results and Discussion

The suitability of jatropha is already justified earlier in terms of MRR and SR where the impacts of current, voltage and pulse timing were evaluated on these said responses. High oxygen contamination of jatropha provides rapid melting and vaporizing, which helps in faster removal. The electrical conductivity of these bio-oils increases with the temperature which rises the field strength and attracts more charge particles inside the ionization zone which facilitates more thermal agitation due to inter-collisions of the molecules. Moreover, higher breakdown strength prolongs the period of dissociation and discharges enormous energy when the breakdown condition is attained. On the other hand, temperature-dependent conductivity incorporates more amount of discharge energy inside the spark zone at high temperatures. Besides these, the lower specific heat helps to control the temperature distributions and predominant heat flux. These are some probable reasons to have better MRR with jatropha than kerosene. Moreover, the higher viscosity and dielectric constant moderate the energy confinement and maintain the susceptibility. Therefore, the combined influences of these two phenomena provide impressive surface properties [19, 20]. Here, the responses are mainly appraised for various flushing ranges, maintaining a constant process condition.

Figure 2a represents the trends of MRR variations with flushing velocity (V_f) while the other parameters are constant ($I = 10$ A, $T_{ON} = 200$ µs, T_{OFF}=20 µs and $P_f = 21$ kg/cm^2). It is observed that the MRR increases proportionally for both dielectrics up to a certain range of 'V_f' and then again it falls. The bio-dielectric assisted machining exhibits impressive MRR up to 0.38 m/s of flushing velocity but beyond this the removal rate falls down up to a certain limit. Regarding kerosene, the MRR rises with 'V_f' up to 0.40 m/s and then falls if the velocity is incremented further. The increment in MRR with 'V_f' may be due to effective flushing consequences where the velocity is potent enough to restrict the evacuation of debris and ensure suitable plight for sparking, melting and vaporization. The effectiveness of debris evacuation improves if the 'V_f' increases but beyond the said limit (0.38 m/s for bio-dielectrics and 0.40 m/s for kerosene), MRR decreases may be due to the presence of an inadequate amount of micro particles in the inter-electrode gap which are not ample for effective discharge [21]. The variation of MRR with flushing pressure (P_f) is represented in Fig. 1b where the 'P_f' is varied between 15–27 kg/cm^2 keeping other process parameters (including the 'V_f') constant. Almost similar types of trends are observed for both the dielectrics, and decrement in MRR is observed after 21 kg/cm^2 of 'P_f' for both dielectrics. Generally, the impact and thrust of flushing at inter-electrode space increases with 'P_f' which assures effective debris removal. So the MRR increases up to 21 kg/cm^2 of 'P_f'.

But flushing pressure beyond the said limit may destroy the reinforcement of charge particles and may interrupt the discharge field present between the electrode

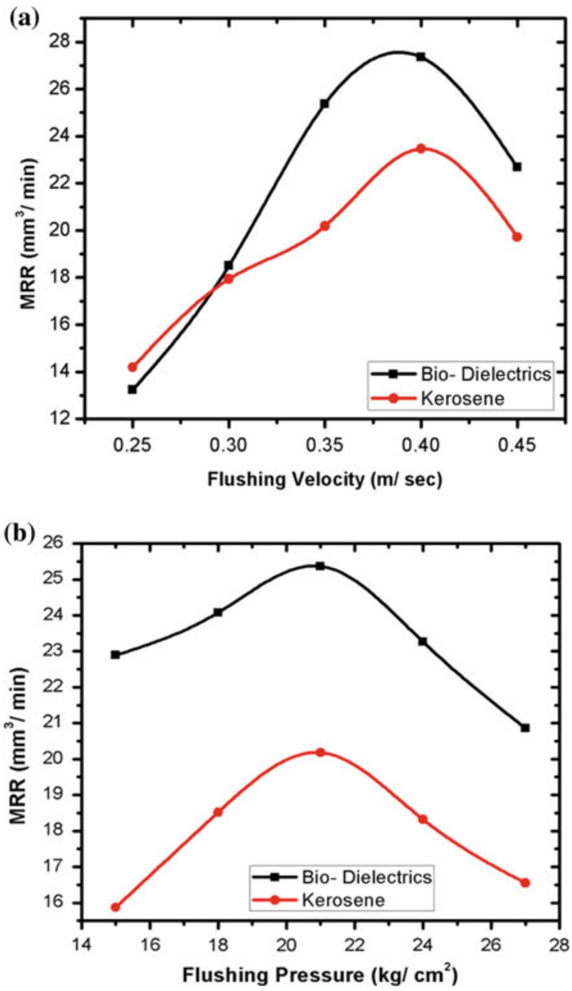

Fig. 2 MRR pattern for different **a** flushing velocities and **b** pressures

and workpiece. Therefore, the effective discharge is hampered which results in poor MRR. The SR decreases with 'V_f' and 'P_f' because they ensure effective debris evacuation which are shown in Fig. 3a and b. The presence of debris particles beyond a certain limit imparts a resistive impact on discharge propagation and may cause the burning of micro debris during the sparking. These may result in enormous heat generation which can cause surface defects and indentions. But 'V_f' and 'P_r' beyond 0.40 m/s and 18 kg/cm^2 escalate the SR because of the unwanted evacuation of loosely bonded particles from the EDMed surface due to the high impulse and thrust of the flushing jet at high pressure and high momentum. But in every respect, the tested bio-dielectric shows impressive responses than kerosene because of their favorable physio-chemical properties which are already discussed earlier. The present study performed a more in-depth analysis of the surface characterization using both dielectric mediums. The qualities of the EDMed surfaces have been judged in terms of surface cracks and thermal defects. Figure 4 represents the thermal defects and crack forms with both the dielectric fluids. It is observed that the EDMed surface developed with jatropha is much affected by thermal influences and the surface cracks are clearly visible. Regarding kerosene, the surface cracks are less and only a few fine lines of surface cracks are observed. These surface imperfections are mainly due to inadequate heat dissipation and poor heat transfer coefficient (h).

The 'h' is influenced by different physical properties mainly by viscosity (μ), density, specific heat (C_p), etc. of the fluid medium. As the densities of both kerosene and jatropha do not differ much, so their impact on 'h' can be ignored. But the jatropha is 5.5 times (approx.) more viscous and has less specific heat than kerosene. Therefore, it exhibits less removal of heat than kerosene because the 'h' inversely varies with 'μ' and directly varies with 'C_p'.

The flushing interactions of EDM are very tough to appraise experimentally as it lasts for a few microseconds only. Engagement of Lagrangian fluidics can accomplish the concern issues as it is a dependable tool to assess the fluid flow interrupted by varying dynamic constraints:

$$\vec{S} = f(x, y, z, t) \tag{2}$$

$$\vec{V} = \frac{d\vec{S}}{dt}_{(x,y,z)} \tag{3}$$

Here, $\overrightarrow{S}$ and $\overrightarrow{V}$ are the position and velocity vectors. Equation 4 presents the energy equation, which is suitable to estimate the heat removal:

$$u\frac{\delta t}{\delta x} + v\frac{\delta t}{\delta y} = \frac{K}{\rho C_p}\frac{\delta^2 t}{\delta x^2} + \frac{\mu}{\rho C_p}\left(\frac{\delta u}{\delta y}\right)^2 \tag{4}$$

Here, u and v are horizontal and vertical velocity components. Figure 5 shows the dissipation patterns for both the mediums, and it is clear that instantaneous temperatures of the developed crater and its surrounding areas are much lesser in the case

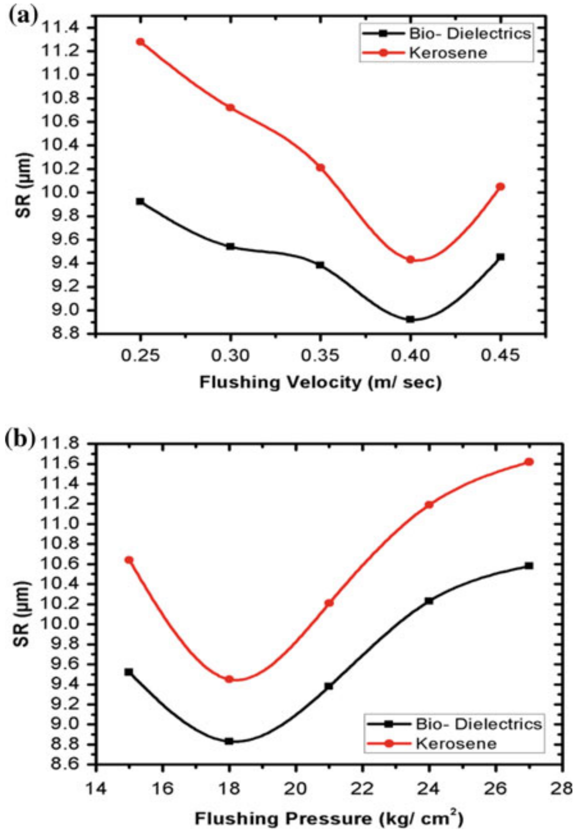

Fig. 3 Variation of SR with flushing **a** velocity and **b** pressure

of kerosene than jatropha. Moreover, a significant fall in temperature is observed for kerosene if the 'V_f' is varied in the range 0.20–0.35 m/s, whereas for jatropha, it is not much significant. So the simulated outcomes distinctly back the issues of less heat dissipation by jatropha than kerosene which evinces more thermal deformity.

4 Conclusion

This article prioritized the issue of flushing and assessed its influences on the responses (especially MRR and SR). Moreover, a detailed analysis of the surface properties is also attempted to ensure a more justified feasibility assessment of jatropha. Therefore, the study elicits the following conclusions:

(i) The flushing consequences have remarkable influences on responses and random selection of flushing conditions may cause unwanted surface irregularities and can hamper the effective removal rate. In this aspect, flushing

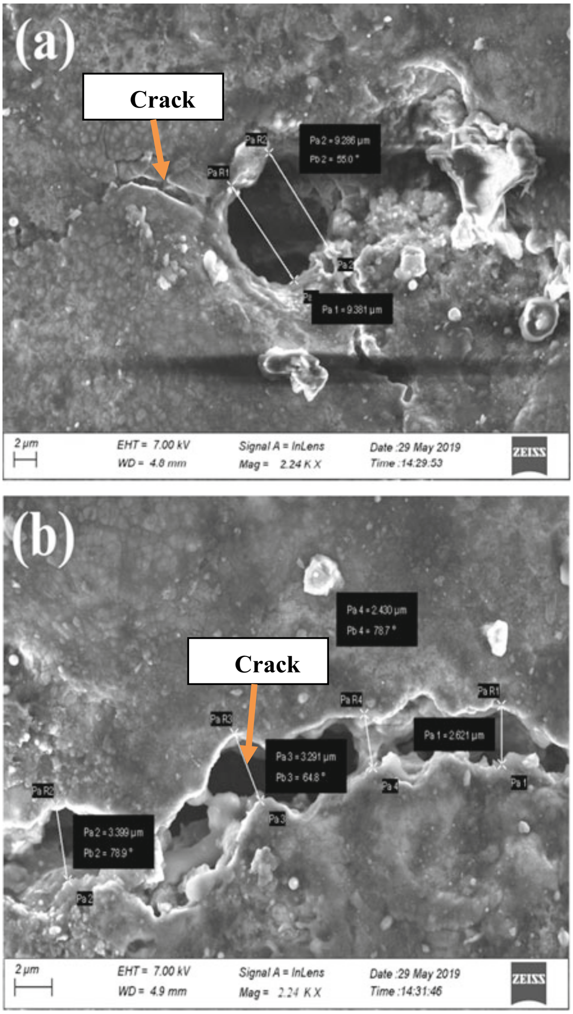

Fig. 4 Surface cracks formed on surface using **a** kerosene and **b** jatropha

velocity and pressure should not exceed more than 0.40 m/s and 21 kg/cm^2 to avoid unwanted reduction of MRR due to the lack of effective discharge.

(ii) Due to less specific heat and high viscosity, the selected bio-dielectric exhibits poor thermal dissipations which affects the surfaces by forming unwanted cracks and indentations at higher values of process parameters. Therefore, high flushing velocity (>0.32 m/s) is recommended for this tested bio-oil, because high velocity increases Reynolds's number of the flow, which facilitates enhanced heat dissipation rate.

(iii) The higher viscous influences of bio-dielectric also ensure better energy confinement and maintain the wettability of EDM surface due to stronger adhesive gripping. So the bio-dielectric facilitates better surface (less SR) if apt

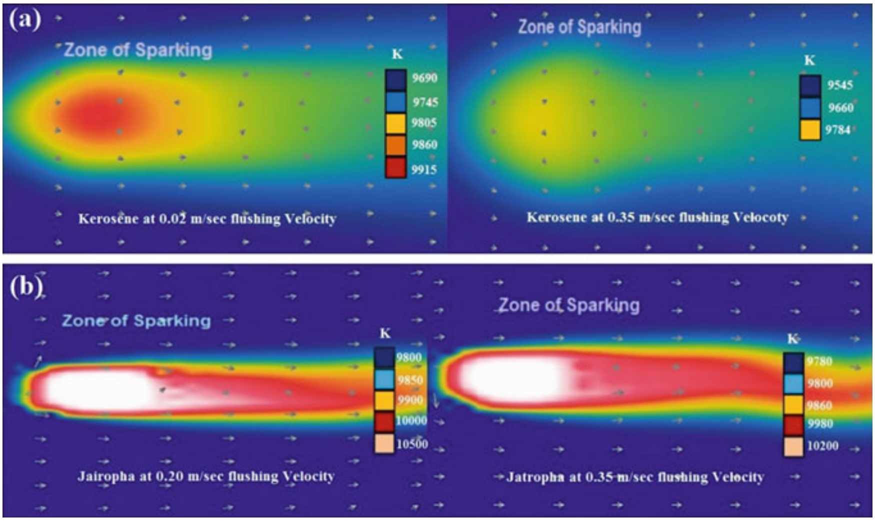

Fig. 5 Heat dissipation patterns and temperature distribution for **a** kerosene and **b** jatropha [18]

flushing conditions are assured. But the velocity and pressure of more than 0.40 m/s and 18 kg/cm^2 cause more SR due to unwanted restoration of loosely bonded particles at high flushing impact.

(iv) It can be acclaimed that at 12 A current, 200 µs ON time, 20 µs OFF time, 0.35 m/s velocity and 21 kg/cm^2 pressure, both dielectrics exhibit maximum MRR and more notably bio-dielectric facilitates 20.50% more removal rate and 10% less SR than kerosene.

The findings which are addressed here are obtained with Ti6Al4V and copper (diameter 10 mm) as workpiece and tool with 50 L of dielectrics (each sample). Therefore, the figures may differ a little for other tool-workpiece sets and dielectrics. However, the present attempt is a collective approach to evaluate the all-round feasibility of jatropha bio-oil as an unconventional dielectric of EDM and obviously, it is found potent enough to ensure suitable responses. So based on the evaluations and referred studies, jatropha can be considered as a reliable and sustainable dielectric if the flushing velocity and pressure are maintained within the said range.

References

1. Modica F, Marrocco V, Copani G, Fassi I (2011) Sustainable micro-manufacturing of micro-components via micro electrical discharge machining. Sustain 24:56–69. https://doi.org/10.3390/su3122456
2. Bommeli B (1983) Study of the harmful emanations resulting from the machining by electro-erosion. Proc Int Symp 469–478

3. Jose M, Sivapirakasam SP, Surianarayanan M (2010) Analysis of aerosol emission and hazard evaluation of electrical discharge machining (EDM). Proc Ind Health 48:478–486. https://doi.org/10.2486/indhealth.MS1127
4. Gutowski T, Dahmus J, Thirez A (2006) Electrical energy requirements for manufacturing processes. Int Conf Life Cycle Eng
5. Leao FN, Pashby IR (2004) A review on the use of environmentally-friendly dielectric fluids in electrical discharge machining. J Mater Process Technol 149:341–346. https://doi.org/10.1016/j.jmatprotec.2003.10.043
6. Nanu D, Nanu A (2008) Perspectives of the dimensional processing through electric erosion processing. Non Conv Technol. 3:61–64. https://doi.org/10.1080/23311916.2016.1270702
7. Valaki JB, Rathod PP, Sidpara AM (2019) Sustainability issues in electric discharge machining. In: Gupta K (ed). Springer, Cham, pp 53–75. https://doi.org/10.1007/978-3-030-03276-0_3
8. Tang L, Du YT (2014) Multi-Objective optimization of green electrical discharge machining Ti-6Al-4V in tap water via Grey-Taguchi method. Mater Manuf Processes 29:507–513. https://doi.org/10.1080/10426914.2013.840913
9. Valaki JB, Rathod PP, Sankhavara CD (2016) Investigations on technical feasibility of Jatropha curcas oil based bio dielectric fluid for sustainable electric discharge machining (EDM). J Manuf Processes. 22:151–160. https://doi.org/10.1016/j.jmapro.2016.03.004
10. Ng PS, Kong SA, Yeo SH (2016) Investigation of biodiesel dielectric in sustainable electrical Discharge machining. Int J Adv Manuf Technol. https://doi.org/10.1007/s00170-016-9572-6
11. Valaki JB, Rathod PP (2015) Assessment of operational feasibility of waste vegetable oil based bio-dielectric fluid for sustainable electric discharge machining (EDM). Int J Adv Manuf Technol. https://doi.org/10.1007/s00170-015-7169-0
12. Valaki JB, Rathod PP (2015) Investigating feasibility through performance analysis of green dielectrics for sustainable electric discharge machining. Mater Manuf Processes. https://doi.org/10.1080/10426914.2015.1070430
13. Li L, Zhao L, Li ZY, Feng L, Bai X (2017) Surface characteristics of Ti-6Al-4V by SiC abrasive-Mixed EDM with magnetic stirring. Mater Manuf Processes 32:83–86. https://doi.org/10.1080/10426914.2016.1151043
14. Feng W, Chu X, Hong Y, Zhang L (2018) Studies on the surface of high-performance alloys machined by Micro-EDM. Mater Manuf Processes 33(6):616–625. https://doi.org/10.1080/10426914.2017.1364758
15. Prakash C, Kansal HK, Pabla BS, Puri S (2017) Experimental investigations in powder mixed electric discharge machining of Ti–35Nb–7Ta–5Zrβ-Titanium alloy. Mater Manuf Processes 32:274–285. https://doi.org/10.1080/10426914.2016.1198018
16. Ahmed N, Ishfaq K, Rafaqat M, Pervaiz S, Anwar S, Salah B (2019) EDM of Ti-6Al-4V: Electrode and polarity selection for minimum tool wear rate and overcut. Mater Manuf Processes. https://doi.org/10.1080/10426914.2019.1594278
17. Ahmed N, Ishfaq K, Moiduddin K, Ali R, Al-Shammary N (2018) Machinability of titanium alloy through electric discharge machining. Mater Manuf Processes 34(1):1–10. https://doi.org/10.1080/10426914.2018.1532092
18. Das S, Paul S, Doloi B (2019) An experimental and computational study on the feasibility of bio-dielectrics for sustainable electrical discharge machining. J Manuf Process 41:284–296
19. Giakoumis EG (2013) A statistical investigation of biodiesel physical and chemical properties and their correlation with the degree of unsaturation. Renew Energy 50:858–878. https://doi.org/10.1016/j.renene.2012.07.040
20. Kiyak M, Aldemir BE, Altan E (2015) Effects of discharge energy density on wear rate and surface roughness in EDM. Int J Adv Manuf Technol. https://doi.org/10.1007/s00170-015-6840-9
21. Li L, Gu L, Xi X (2012) Influence of flushing on performance of EDM with bunched electrode. Int J Adv Manuf Technol 58(1):187–194. https://doi.org/10.1007/s00170-011-3357-8

Comparative Evaluation of Machining Performance of Nimonic 263 in Powder Mixed EDM

Deepti Ranjan Sahu and Amitava Mandal

Abstract This paper aims at a comparative investigation into the machining performance of Nimonic 263 by graphite micro powder mixed Electrical Discharge Machining (PMEDM) process. Material removal rate (MRR), tool wear rate (TWR), and average surface roughness (R_a) of the machined surface are the performance parameters used to evaluate the machining performance both with normal and reverse polarity. Pulse duration (T_{on}), peak current (IP), and duty factor (DF) are the process variables used for both the polarity conditions. The optimum condition for each of the performance measures has been determined using the response surface method (RSM). Residual stress values have been compared for the machined surface obtained at parametric conditions for optimum surface roughness for both the polarity conditions. MRR obtained for normal polarity condition has been found to be higher than that for reverse polarity condition. Using reverse polarity has been found to increase the TWR as compared to normal polarity conditions. The machined surface obtained using reverse polarity has a better surface finish as compared to that obtained using the normal polarity condition. Using reverse polarity has been found to be helpful in reducing the residual stress by 73.52–88.50% as compared to the normal polarity condition.

Keywords EDM · Graphite powder mixed EDM · Polarity · Residual stress · Surface roughness · Tool wear rate · Material removal rate

1 Introduction

EDM is a non-conventional machining process governed by the mechanism of material removal by melting and vaporization. It can machine electrically conducting materials of any hardness [1, 2]. But low MRR and poor surface quality limit its capabilities [3]. PMEDM can overcome these limitations to a great extent by improving surface quality and producing high MRR [4, 5, 6, 7]. Nimonic 263 is a nickel-based

D. R. Sahu (✉) · A. Mandal
Department of Mechanical Engineering, Indian Institute of Technology (ISM), Dhanbad 826004, India
e-mail: deeptiranjan_sahoo@yahoo.in

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

M. S. Shanmugam et al. (eds.), *Advances in Modern Machining Processes*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-19-7150-1_2

superalloy having wide application in aerospace engines and gas turbines but is quite difficult to machine by conventional machining processes [8]. Previous researchers [4, 9] have found that the EDM principle can machine this superalloy. However, there is one drawback that can make components machined by EDM or PMEDM process unsuitable for some critical applications. That drawback is the tensile residual stress on the machined surface [3]. Tensile residual stress reduces the fatigue life of the components which restricts their use in applications, viz., aerospace components. In their previous work [4], the authors observed that the addition of graphite micro powder to the dielectric fluid significantly improved the surface quality of the machined surface. They observed that although graphite PMEDM reduced the residual stress on the machined surface as compared to the conventional EDM over the same range of machining parameters, still the value of tensile residual stress was high. In this regard, the authors have attempted to mitigate the tensile residual stress on the components machined by graphite PMEDM by reversing the polarity. Apart from residual stress, the authors also present a comparative study of the response parameters, viz., MRR, TWR, and R_a and their variation with respect to pulse duration, peak current, and duty factor in both normal and reverse polarity conditions. For comparison, the authors have taken the data for TWR and R_a in graphite PMEDM with normal polarity from their previous work [4].

2 Materials and Methods

2.1 Materials

Nimonic 263 plate with dimensions 100 mm × 50 mm × 5 mm has been taken as the workpiece material. Before conducting the machining operation the workpiece has been polished with sandpaper for producing a clean and finished surface. A copper rod with a cylindrical shape and diameter of 9 mm has been taken as the tool electrode. The bottom surface which participates in the machining process has been brought to a leveled flat surface by face turning operation before using it for the machining process. Graphite micro powder of Sigma Aldrich make has been added to EDM oil to be used as the dielectric fluid. For carrying out the flushing operation and circulating the powder mixed dielectric fluid, a separate container with a pump as shown in Fig. 1 has been used while performing the experiments.

2.2 Methodology

Sparkonix EDM machine with model number ZNC/EDM 35 as shown in Fig. 1 has been used for conducting the machining operation. T_{on}, IP, and DF are the parameters taken as process variables. Gap voltage, spark time, and sensitivity have been kept

Fig. 1 Experimental setup

constant at 30 V, 3 s, and 50%, respectively. The powder concentration in EDM oil has been kept constant at 2 g/l. A total of 15 experiments with three center points and three levels for each of the process variables have been conducted following the Box-Behnken design of the Response surface method (RSM). The three levels of T_{on} are 20, 60, and 100 µs; the three levels for IP are 6 A, 12 A, and 18 A; the three levels for DF are 42, 60, and 78%. In normal polarity, i.e., positive polarity condition, the tool electrode is connected to the positive terminal and the workpiece is connected to the negative terminal, whereas in reverse polarity condition, the tool electrode is connected to the negative terminal and the workpiece is connected to the positive terminal. With the above parametric condition, the experiments have been conducted with normal polarity as well as reverse polarity. MRR, TWR, and R_a have been studied as the performance parameters. MRR and TWR have been measured by dividing the difference between the weight of the workpiece and tool before and after machining, respectively, by the machining time. A precision weighing machine (make: Sartorius -BSA4202S-CW) has been used for measuring the weight. R_a has been measured by surface profilometer (Mitutoyo SJ210, sampling length = 2.4 mm, cut-off length = 0.8 mm). The analysis of variance has been conducted, regression equations have been developed, and optimum parametric conditions for the responses have been determined by the response surface method. Residual stress on the machined surface obtained at optimum R_a value has been measured using the X-ray diffraction technique (make: PANalytical EMPYREAN).

3 Results and Discussion

Table 1 presents the parametric condition and corresponding performance measures. Analysis of variance has been conducted and the relevant information has been presented in Table 2. The performance measures (TWR and R_a) for normal polarity condition have been taken from the previous work of the authors [4]. The comparative trends of the performance measures for both the polarity conditions have been presented in Figs. 1, 2, and 3.

The acceptability of the developed regression models are verified by analysis of variance using Minitab 17 statistical software with 95% confidence level. The information from ANOVA analysis is summarized in Table 2. The obtained p values are used to identify the significant factors.

For MRR, in both the polarity conditions, all the input variables have been found to be significant. For normal polarity, duty factor's contribution has been found to be maximum, whereas in reverse polarity, peak current's contribution has been found to be maximum. In case of TWR, duty factor has been found to be insignificant in both the polarity conditions with least contribution. For normal polarity, peak current has the maximum contribution, whereas for reverse polarity, pulse duration has the maximum contribution. For R_a, in normal polarity, all the factors are found to be significant, pulse duration being the highest contributing factor. In reverse polarity, the duty factor has been found to be insignificant, whereas pulse duration and peak current are found to be significant with peak current being the highest contributing factor.

P values for lack of fit for all the models are found to be greater than 0.05 showing acceptable fitness of all the models. The R^2 values are also within acceptable ranges. Hence, the predicting capability of the models can be relied upon for the considered range of process parameters.

Table 1 Input parameters and performance measures

Expt. No	Input parameters			Normal polarity			Reverse polarity		
	T_{on} (coded)	IP (coded)	DF (coded)	MRR (mg/min)	TWR (mg/min)	R_a (μm)	MRR (mg/min)	TWR (mg/min)	R_a (μm)
1	– 1	– 1	0	248.00	6.67	4.82	10.00	22.00	1.36
2	– 1	0	– 1	185.00	15.00	4.87	19.00	47.00	2.30
3	– 1	1	0	250.00	16.67	6.81	40.00	106.00	2.68
4	0	– 1	– 1	187.00	3.00	6.29	10.82	17.00	2.34
5	1	0	1	320.00	10.00	5.30	12.00	17.50	3.44
6	0	1	1	398.00	12.00	6.32	33.00	51.00	4.50
7	1	0	– 1	245.00	6.50	7.92	16.00	31.00	3.45
8	1	– 1	0	226.67	3.50	7.45	8.00	16.00	2.47
9	0	0	0	294.00	8.00	7.11	29.00	49.00	2.60
10	– 1	0	1	272.00	14.67	4.68	36.00	80.00	2.19
11	0	0	0	286.67	6.67	6.68	30.00	46.00	2.72
12	0	0	0	302.00	7.00	6.67	30.00	45.00	2.50
13	0	– 1	1	245.00	11.50	5.71	14.00	17.00	2.31
14	1	1	0	375.00	10.00	7.11	10.00	18.00	4.37
15	0	1	– 1	220.00	20.00	7.49	31.00	50.00	4.47

Table 2 Analysis of variance

Source	DOF	Adj. SS	Adj. MS	F	P	Contribution (%)
For MRR $_{normal\ polarity}$						
T_{on}	1	5600.4	5600.4	29.06	0.003	10.68
DF	1	19,800.5	19,800.5	102.75	0.000	37.78
IP	1	14,140.0	14,140.0	73.38	0.000	26.97
Square	3	2921.6	973.9	5.05	0.057	5.57
Interaction	3	8989.3	2996.4	15.55	0.006	17.15
Error	5	963.5	192.7			1.83
Lack of fit	3	845.9	282.0	4.79	0.177	1.61
Pure error	2	117.6	58.8			0.22
Total	14	52,415.3				
S = 13.8816; R^2 = 98.16%; R^2 (predicted) = 73.67%; R^2 (adjusted) = 94.85%						
For MRR $_{reverse\ polarity}$						
T_{on}	1	435.12	435.125	121.68	0.000	25.34
DF	1	41.31	41.314	11.55	0.019	2.41
IP	1	633.32	633.324	177.11	0.000	36.89
Square	3	282.66	94.220	26.35	0.002	16.46
Interaction	3	306.60	102.199	28.58	0.001	17.86
Error	5	17.88	3.576			1.04
Lack of fit	3	17.21	5.738	17.21	0.055	1.00
Pure error	2	0.67	0.333			0.04
Total	14	1716.90				
S = 1.89102; R^2 = 98.96%; R^2 (predicted) = 83.87%; R^2 (adjusted) = 97.08%						
Source	DOF	Adj. SS	Adj. MS	F	P	Contribution (%)
For TWR $_{normal\ polarity}$						
T_{on}	1	66.131	66.131	98.25	0.000	19.68
DF	1	1.681	1.681	2.50	0.175	0.50
IP	1	144.500	144.500	214.69	0.000	42.99
Square	3	45.632	15.211	22.60	0.002	13.58
Interaction	3	74.798	24.933	37.04	0.001	22.25
Error	5	3.365	0.673			1.00
Lack of fit	3	2.403	0.801	1.66	0.397	0.71
Pure error	2	0.963	0.481			0.29
Total	14	336.107				100.00
S = 0.820404; R^2 = 99.00%; R^2 (predicted) = 87.92%; R^2 (adjusted) = 97.20%						
For TWR $_{reverse\ polarity}$						

(continued)

Table 2 (continued)

Source	DOF	Adj. SS	Adj. MS	F	P	Contribution (%)
T_{on}	1	3719.53	3719.53	146.90	0.000	39.62
DF	1	52.53	52.53	2.07	0.209	0.56
IP	1	2926.12	2926.12	115.56	0.000	31.17
Square	3	340.23	113.41	4.48	0.070	3.62
Interaction	3	2221.81	740.60	29.25	0.001	23.67
Error	5	126.60	25.32			1.35
Lack of fit	3	117.94	39.31	9.07	0.101	1.26
Pure error	2	8.67	4.33			0.09
Total	14	9386.83				100.00
S = 5.03198; R^2 = 98.65%; R^2 (predicted) = 79.69%; R^2 (adjusted) = 96.22%						
Source	DOF	Adj. SS	Adj. MS	F	P	Contribution (%)
For $R_{a\ normal\ polarity}$						
T_{on}	1	5.4372	5.43725	81.92	0.000	35.37
DF	1	2.5837	2.58372	38.93	0.002	16.81
IP	1	1.5031	1.50312	22.65	0.005	9.78
Square	3	2.5907	0.86358	13.01	0.008	16.85
Interaction	3	2.9272	0.97572	14.70	0.006	19.04
Error	5	0.3319	0.06637			2.16
Lack of fit	3	0.2105	0.07016	1.16	0.495	1.37
Pure error	2	0.1214	0.06069			0.79
Total	14	15.3738				100.00
S = 0.257627; R^2 = 97.84%; R^2 (predicted) = 76.32%; R^2 (adjusted) = 93.96%						
For $R_{a\ reverse\ polarity}$						
T_{on}	1	3.3797	3.37974	86.17	0.000	27.73
DF	1	0.0020	0.00200	0.05	0.830	0.02
IP	1	7.1106	7.11060	181.30	0.000	58.34
Square	3	1.4118	0.47059	12.00	0.010	11.58
Interaction	3	0.0869	0.02898	0.74	0.573	0.71
Error	5	0.1961	0.03922			1.61
Lack of fit	3	0.1721	0.05736	4.78	0.178	1.41
Pure error	2	0.0240	0.01201			0.20
Total	14	12.1871				100
S = 0.198039; R^2 = 98.39%; R^2 (predicted) = 76.97%; R^2 (adjusted) = 95.49%						