Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 14, Special Issue 1, 2026
DOI (Journal): 10.37591/JoPC

https://journals.stmjournals.com/jopc

Review JoPC

Thermal Interaction Analysis Between Flexible Magnetic Abrasive Brush and Aluminium Alloy During Single-Pole MAF

Chandan Kumar Jha[1], Kheelraj Pandey[2,*], Vineet Srivastava[3], Ashwani Sharma[4], Gaurav Raj Pandey[5]

Abstract

Magnetic Abrasive Finishing (MAF) is a precision surface-finishing approach that employs magnetic abrasive particles (MAPs) within a managed magnetic field to eliminate micro-level material and enhance surface condition. In the finishing process, the friction created between the workpiece and the flexible magnetic abrasive brush (FMAB) leads to heat accumulation, which may badly affect the surface integrity. This study focuses on investigating the temperature distribution at the FMAB–workpiece interface to decrease thermal effects and enhance finishing performance. The influence of key constraints—polishing speed (500–1500 RPM), feed rate (1.5–5.5 mm/s), working gap (6–7 mm), and Keller's etchant concentration (2.5–7.3% wt./wt.)—was studied. Before finishing, the aluminium alloy samples were pre-etched with Keller's reagent to improve processing efficiency. An L16 factorial experimental design was implemented, and interface temperatures were measured at 10-minute intervals using an infrared thermometer. The study focuses on the combined effects of FMAB rotational speed, working gap, and feed rate on interface temperature. Results express that optimising these process parameters extensively reduces thermal load. The best possible conditions identified—1500 RPM FMAB speed, 6 mm working gap, 1.5 mm/s feed rate, and 7.3% wt./wt. Keller's concentration produced a minimum contact temperature of 28.41°C, contributing to improved machining efficiency and surface quality.

Keywords: Work Brush Temperature (WBT), Magnetic Abrasive Finishing (MAF), Chemical Machining Process (CMP), Magnetic Abrasive Particles (MAP), Single-pole Magnetic Abrasive Finishing (SPMAF), Keller's reagent, Flexible Magnetic Abrasive Brush (FMAB), Analysis of Variance (ANOVA).

***Author for Correspondence**
Kheelraj Pandey

[1]Research Scholar, Department of Mechanical Engineering, Amity University, Lucknow, India
[2,4]Assistant Professor, Department of Mechanical Engineering, Amity University, Lucknow, India
[3]Associate Professor, Department of Mechanical Engineering, Thaper University, Patiala, India
[5]PG Scholar, Department of Mechanical Engineering, Amity University, Lucknow, India

Received Date: December 11, 2025
Accepted Date: January 05, 2026
Published Date: March 25, 2026

Citation: Chandan Kumar Jha, Kheelraj Pandey, Vineet Srivastava, Ashwani Sharma, Gaurav Raj Pandey. Thermal Interaction Analysis Between Flexible Magnetic Abrasive Brush and Aluminium Alloy During Single-Pole MAF. Journal of Polymer & Composites. 2026; 14 (Special Issue 1): S1906-S1918p.

INTRODUCTION

Aluminium alloys are broadly used in various industries for their extraordinary properties, containing being lightweight, high strength, and corrosion resistant. These alloys predominantly consist of aluminium (Al) as the base metal, with additional mixing elements like magnesium, nickel, silicon, zinc, manganese, tin, and copper. Aluminium compounds are generally separated into two main groups: casted compounds and wrought compounds, which are consequently classified as heat-curable and non-heat-curable. About 85% of aluminium alloys are widely used in the production of wrought items, rolled plates, foils, and extrusions. Cast aluminium compounds, especially those with a silicon substance ranging from 4% to

13%, are widely used in engineering, space technology, and health applications due to their exceptional mechanical properties. For purposes meant for significant precision in industry sectors such as aerospace, automotive, and medical, achieving an ultra-smooth, mirror-like, and defect-free surface finish on aluminium alloys is needed. Many finishing techniques have been formed to improve the surface quality of aluminium alloys, with conventional/traditional machining processes (CMP), burnishing, vibratory finishing, electropolishing, MAF, and MAF integrated with an electrolytic procedure. Each of these methods offers distinct advantages; however, achieving the required surface accuracy while preventing material damage remains a challenge. The effectiveness of these finishing processes is affected by various factors, including the heat generated from friction, the roughness of the surface, and the amount of removed material. The significant challenges in finishing aluminium alloys are the development of surface imperfections, such as hillocks and microdefects. These irregularities need to be eliminated to attain the desired condition of the surface finish. MAF has attracted considerable interest in this context because of its capacity to deliver enhanced surface finishes while minimizing surface imperfections. In MAF, an FMAB acts as a tool with multiple cutting edges that removes material through monitored abrasion under a magnetic field. However, during this process, frictional forces, shear forces, and rubbing actions generate heat at the metal surface, which may alter the material's molecular structure and cause thermal damage. To concentrate this issue, this investigation proposes a unique finishing approach that combines MAF with Keller's reagent etching to improve surface finishing efficiency while minimizing thermal damage. The key constraints, including polishing speed, feed rate, machining gap, and Keller's reagent concentration levels, were optimized to achieve a defect-free surface. Surface temperature was supervised using an infrared thermometer, and the process was analysed using MINITAB, MATLAB, and ANOVA methods. The findings aim to improve finishing efficiency and confirm superior surface integrity for high-performance purposes.

LITERATURE REVIEW

Hou et.al. [1] examined the thermal characteristics of MAF. Abrasive particles were used to polish the ceramic rollers through a combination of mechanical and chemo-mechanical interactions. Found that temperature played the main role in chemical reactions and material removal rates. Proper control of temperature, along with abrasive selection, pressure and speed, enhances the high-quality finishing of ceramic rollers. Davies et.al. [2] conducted measurements of temperature in material removal processes. The turning process was used for the material removal process. High temperatures cause residual stress, tool wear and workpiece deformation. Combining thermocouples, infrared imaging, and simulations improves accuracy. Higher cutting speeds cause extreme temperatures (1000°C). Shen et.al. [3] researched the thermocouple fixation technique for the measurement of grinding temperature. The epoxied thermocouple technique offers better accuracy and reliability in temperature measurement. Cooling effectiveness in grinding depends on fluid film behaviour. Wet grinding can drastically reduce workpiece temperatures, but only under specific conditions. MQL is beneficial for lubrication but does not help significantly in cooling. Kumar et.al. [4], the temperature within the work specimen during the plane. MAF is analysed using the finite element method (FEM). FEM-based modelling provides accurate predictions for magnetic potential and temperature rise. MAF process parameters significantly impact workpiece temperature, influencing finishing quality. The model helps optimize machining conditions for precision finishing while controlling thermal effects. Mulik et.al. [5] considered the Mechanism of Surface Finish in the Ultrasonic Vibration MAF procedure. Found that the temperature in the finishing zone varied between 33°C and 46°C, and the ambient temperature was in the range of 20°C and - 23°C. Low temperature prevents thermal damage. Mulik et.al. [6] investigated the ultrasonic vibration with MAF of AISI 52100 sheets of steel with the use of SiC abrasive. Low temperature is responsible for material removal without any thermal effects. Mulik et.al. [7] conducted the experimental investigation and demonstration of temperature at the work-brush edge during the ultrasonic vibration MAF process. Temperature affects surface integrity, finishing accuracy and the cutting mechanism. The mathematical model was developed using the Buckingham-π theorem to forecast temperature with UAMAF. Found that a maximum of 46°C is suitable for the finishing process. Kim et al. [8] investigated surface texture and die temperature effect friction and lubrication during the forging process. Higher die temperature (150°C) degraded lubricant performance, causing higher friction and changing the ring geometry. Higher temperature increases friction and surface wear, especially when lubrication fails. Uneven temperature distribution leads to asymmetric deformation, affecting product quality. The surface finish worsens at high temperatures due to increased friction and reduced lubrication efficiency. Kanish et al. [9] established a model based on fuzzy logic techniques to forecast enhancements in surface irregularity during MAF. Temperature changes can affect the hardness and ductility of SS316L stainless steel. Higher temperatures might impact the wear resistance and behaviour of magnetic abrasive particles (MAPs). Mishra et.al. [10] obtained the temperature of the work-brush interface in the MAF process. Frictional heat is generated by the rubbing mechanism of MAPs aggregations on the surface of workpiece. The temperature response range over the workpiece-MAP boundary was 34°C to 51°C under different operating conditions. Thermocouples of variety-K were used to predict temperature, while finite element analysis (FEA) simulations validated experimental findings. The temperature in MAF remains low, ensuring no thermal defects in the workpiece. Khajehzadeh et al. [11] performed an experimental learning to examine the tool temperature in Ultrasonically Assisted Turning (UAT) of aerospace-grade aluminium. UAT can reduce cutting temperature, but only when vibration amplitude and feed rate are optimized. Higher work velocity and feed rate increase tool temperature, affecting tool wear and surface quality. Excessive vibration amplitude leads to temperature rise due to greater tool movement and heat generation. Low-temperature UAT (optimal amplitude and low feed rate) improves surface roughness and life of tool. Wang et al. [12] investigated how the rolling temperature during finishing influences the microstructure properties of non-quenched, tempered bainite steel. The temperature as a result of finishing rolling significantly impacts the structure at the micro-level and properties that are mechanical in nature of bainite steel. Higher temperatures (870°C) improve toughness and ductility but reduce strength. In contrast, lower temperatures (750°C-800°C) increase strength, albeit at the expense of lower impact resistance due to martensite formation. The stability of retained austenite and grain boundary distribution also changes with temperature, influencing overall material performance. Singh et.al. [13] experimented on the impact of temperature in MAF of Aluminium 6060. Surface temperature rise is low due to the high thermal conductivity of aluminium, making it a thermally stable process. Voltage and abrasive weight significantly affect temperature rise by increasing friction and the magnetic normal force. Developed a semi-empirical model using the Buckingham-π theorem to predict temperature rise in different materials. The model was validated with an average error of 7.31% for aluminium 6060 and was extended successfully to mild steel, showing a higher temperature rise due to the lower thermal conductivity. Singh et al. [14] performed a temperature analysis on the MAF process of aluminium 6060, utilizing the finite element technique for their study. Simulated magnetic flux distribution (0.429 Tesla to 1.263 Tesla for current between 3.0 ampere and 6.0 ampere) and distribution temperature surface between (27.33°C to 34.92°C) with the use of ANSYS 16 software. The FEA model successfully predicts the thermal and magnetic behaviour of the MAF process and can be used for optimizing finishing conditions. The above-mentioned methods were used for the surface finishing of aluminium alloy/steels and controlling the surface temperature while removing the material from the surface. In addition to the above, a novel new method for finishing of alloy is proposed, i.e., the combined effect of MAF with etching based on Keller's component.

In the proposed method of finishing, an etching agent is used as Keller's reagent before the finishing material is etched in Keller's reagent at different concentration levels, which helps to weaken the chemical bonding of the material and due to that, material removal takes place efficiently. Alumina is used as an abrasive, and a slurry of alumina was also applied during the finishing process that enhance finishing process efficacy. In the above literature review, none of the researchers studied the work brush temperature using the proposed method. The objective of the study is to investigate the impact of various process variables, such as speed of FMAB, working gap, and Keller's mixture for etching at different concentration levels and feed rates, temperature of the interactive boundary between FMAB and work material and induce a contrast between the distinct procedures using the infra-red thermometer. The process is optimized using MINITAB and MATLAB **s**oftware, along with ANOVA techniques.

METHODOLOGY

Experimental Framework and Procedure

The framework for the experiment has been shown in Figure 1(a), which consists of a machine spindle, finishing tool, FMAB, polishing tray and iron stacks. The finishing tool is a cylindrical disk made of aluminium material, specially designed to accommodate magnetic stacks of 25mm diameter. The quantity of magnetic stacks inside the cylinder is necessary to initiate a magnetic arena in the area for finishing. The magnetic arena occurring in the finishing zone is increased by installing iron stacks below the polishing tray. The workpiece in the present study is the work material of aluminium compound of measurement (10mm-length×10mm-width×1mm-height), which is kept on the polishing tray. The picture of the raw aluminium work-material sample is shown in Figure 1(b). FMAB on the tool face shown in Figure 1(c) is formed because of the magnetic arena between the instrument tool and workpiece to execute the finishing process.

The FMAB is composed in a ratio of 60:40 of alumina and iron particles by weight, which contributes towards the formation of a brush weighing 5g. The magnetic tool is resting on the pole of a milling machine apparatus, and as the spindle rotates, it generates a circular motion of the FMAB. This tangential cutting action of the abrasive particles effectively removes material from the aluminium alloy workpiece. The larger diameter iron particle during the cutting mechanism of the abrasive particles exerts a downward force on it to cause penetration in the work material, to increasing the efficacy of the polishing mechanism. The alumina slurry was introduced in the finishing zone at an interval of every 5 minutes during the finishing process.

The FMAB and the workpiece remain in permanent contact throughout the finishing procedure. Contact between the FMAB and the work material generates friction, leading to an increase in contact temperature, which should be optimized to enhance finishing efficiency. The magnetic abrasive brush under the influence of magnetic field of 0.4 T is perfectly stable throughout the finishing duration that ensures the formation of structured chain of MAPs particles i.e., the large diameter iron particle and small sized abrasive particles. This ensures consistent finishing performance under the applied magnetic field strength with uniform MAPs chain at optimum process parameters. The magnetic abrasive brush makes a soft, multi-point contact with the work surface. This consequences in low heat generation throughout the machining process. The friction includes both sliding and rolling at micro-level interactions, which causes only a minor and evenly circulated rise in temperature at the tool–workpiece crossing point. Air gaps, slurry, and help in effective cooling of the finishing surface.

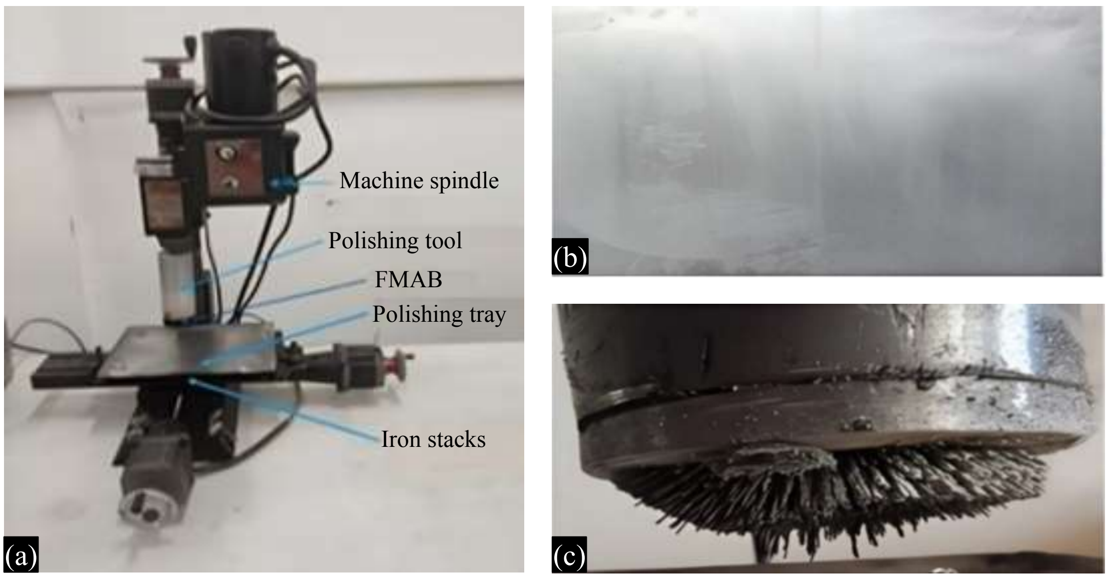


Figure 1. (a) SPMAF experimental framework (b) Aluminium alloy workpiece (c) FMAB

ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

Therefore, the hazard of thermal damage is low, and surface burns, microcracks, or metallurgical changes are hardly observed. In contrast, rigid or conventional tools have a hard and unceasing contact with the surface and the friction is sliding in nature, which produces more heat. This leads to the generation of local hot spots, poor cooling effect, and a great risk of thermal damage such as burns, microcracks, leading to the degradation of surface quality. The etching of the aluminium alloy was done before the finishing process with Keller's reagent. Keller's mixture is composed of HCl, HF, and HNO_3, and the constituents were varied as per the experimental design in 95 ml of distilled water. The etching of the raw aluminium workpiece was done for 60 minutes.

Planning of Experiment

The four input parameters, as mentioned in the Table 1 were chosen to conduct the experiments based on the L-16 factorial design and corresponding contact temperature between workpiece and cutting tool recorded in Table 2.

Experimental Data Analysis

The testing utilized an L-16 factorial design implemented in MINITAB 17, which contains a linear model. This approach led to the formulation of the following response equation (1).

$$T\ (^{\circ}\text{C}) = \alpha_o + \sum_{i=1}^{n} \beta_i x_i + \in \quad (1)$$

In this study, T (°C) represents the boundary temperature between the aluminium alloy workpiece and FMAB, n denotes the trial of procedure experimental parameters, β_i is the factor, x_i characterizes the linear experimental terms of input variables, and ε is a constant for error.

Table 1. Process parameter particulars.

Symbols	Description	Level on the smaller Side	Level on the higher side
X_1	FMAB speed (RPM)	500	1500
X_2	Working gap (mm)	6	7
X_3	Feed rate (mm/s)	1.5	5.5
X_4	Etchant concentration (% wt./wt.)	2.5	7.3

Table 2. Contact temperature between FMAB and aluminium alloy workpiece for Individual investigational test.

Exp. test no.	FMAB speed (RPM)	Working gap (mm)	Feed rate (mm/s)	Etchant conc. (% wt./wt.)	Contact temp. (ºC)
1	1500	6	5.5	2.5	26.42
2	500	7	5.5	2.5	24.58
3	1500	6	5.5	7.3	27.51
4	500	7	1.5	7.3	24.93
5	500	6	1.5	2.5	24.85
6	500	6	1.5	7.3	25.27
7	500	6	5.5	2.5	24.63
8	500	7	1.5	2.5	24.58
9	1500	7	1.5	7.3	26.33
10	1500	7	1.5	2.5	26.13
11	500	6	5.5	7.3	24.56
12	1500	6	1.5	7.3	28.47
13	500	7	5.5	7.3	24.43
14	1500	7	5.5	2.5	25.56
15	1500	7	5.5	7.3	26.33
16	1500	6	1.5	2.5	28.02

Table 3. Variance analysis for response equation (2).

Source	DF	Adj.SS	Adj.MS	F	p	Remark
Model	11	25.7481	2.3407	212.55	0.00	
Linear	04	22.7613	5.6903	516.71	0.00	
X_1	1	17.9352	17.9352	1628.62	0.00	
X_2	1	2.9412	2.9412	267.08	0.00	
X_3	1	1.2996	1.2996	118.01	0.00	
X_4	1	0.5852	0.5852	53.14	0.002	$F^{standard}_{(0.05,11,4)} = 5.94$
2-Way interaction	5	2.5322	0.5064	45.99	0.001	F^{model}= 212.55
$X_1 \times X_2$	1	1.7424	1.7424	158.22	0.00	$F^{model} > F^{standard}_{(0.05,11,15)}$ ⇨ $212.55 > 5.94$
$X_1 \times X_3$	1	0.1806	0.1806	16.04	0.015	
$X_1 \times X_4$	1	0.2401	0.2401	21.80	0.010	The statistical model for the contact temperature. between FMAB and aluminium alloy, the workpiece is accurate
$X_2 \times X_3$	1	0.3660	0.3660	33.24	0.004	
$X_3 \times X_4$	1	0.0030	0.0030	0.27	> 0.05	
3-Way interaction	2	0.4546	0.2273	20.64	0.008	
$X_1 \times X_2 \times X_3$	1	0.1521	0.1521	13.81	0.021	
$X_1 \times X_3 \times X_4$	1	0.3025	0.3025	27.47	0.006	
Error	4	0.0440	0.0110		0.76	
Total	15	25.7921				

The experimental data were analysed using Analysis of Variance (ANOVA), with the ANOVA Table 3. for contact temperature between FMAB and aluminium alloy workpiece accessible in Table 2. To advance into deeper insights for understanding the influence of process experimental parameters on MRR, a multivariable equation of regression was derived and is provided as Equation 2. Output response, i.e., T (˚C), and the process experimental parameters (X_1, X_2, X_3, X_4) exhibit a strong correlation, with an adjusted R^2 (adj.) value of 99.36% at a 95% confidence interval and a minimal error of ±0.22.

$$T(\,^0C) = 18.97 + 0.01599X_1 + 0.616X_2 + 0.515X_3 + 0.1681X_4 - 0.002003X_1X_2 + 0.001654X_1X_3 - 0.000098X_1X_4 - 0.0438X_2X_3 - 0.0544X_3X_4 + 0.000195X_1X_2X_3 + 0.000057X_1X_3X_4 \quad (2)$$

DISCUSSION ON THE RESULTS

Consequence of Process Experimental Parameters on Contact Temperature between FMAB and Workpiece

The sequential representation of the process effect on experimental variables, i.e., FMAB speed, gap between Workpiece and FMAB, feed-rate variation of the workpiece and Keller's mixture concentration on the contact temperature between FMAB and aluminium alloy workpiece, has been shown in Figure 2(a). In Figure 2(a), it is highlighted that the contact temperature between the FMAB and the workpiece increases with the rise in the speed of the FMAB. The rationale can be that the increase in FMAB speed increases the frictional contact between the particles of abrasive and the work-material surface, thereby raising the temperature of the contact surface. The contact temperature decreases with a larger FMAB-workpiece gap, while an increase is observed at a lower FMAB-workpiece gap. The reason can be that at a lower FMAB-workpiece gap, the friction is greater at the contact surface, which raises the contact temperature. The converse phenomenon is observed when the FMAB workpiece is at a larger gap. A decreasing trend is observed for the rate of feed variation of the workpiece with contact temperature. At lower feed rate, the temperature of the contact between FMAB and the work material is observed to be on the rising side because interaction persists for a longer time duration, due to which the contact temperature increases. At a higher feed rate, the contact between FMAB and the aluminium alloy workpiece persists for a shorter time duration, resulting in a decrease in contact temperature. The

Journal of Polymer & Composites
Volume 14, Special Issue 1
ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

oxidation of aluminium atoms occurs due to the etching phenomenon of the aluminium alloy workpiece in Keller's reagent. When the concentration is small, i.e., 2.5% wt./wt. The oxidation rate and the molecular collisions between the atoms of the workpiece are on the lower side, resulting in a contact temperature at the lowest level.

However, with the increase in the concentration of Keller's reagent from (2.5–7.3) %wt./wt., the atomic oxidation from the workpiece due to etching mechanism and the molecular collision of workpiece atoms in the etching solution increases. The aforesaid phenomenon causes an increase in increasing the contact temperature.

Optimization of Objective Functions using fmincon function

Regression equation derived from the experimental data presented in Table 2 was refined using the standard fmincon function in MATLAB 16, adhering to the specified constraints outlined below. The maximum contact temperature of 28.41 °C at the FMAB–aluminium alloy interface was obtained experimentally under optimum parameters (Table 4). The value predicted by the thermal model (Equation 2), shown in Figure 2(b), deviated by only ±0.22 °C, thereby validating the proposed model.

$$500 \le X_1 \le 1500;\ 6 \le X_2 \le 7;\ 1.5 \le X_3 \le 5.5;\ 2.5 \le X_4 \le 7.3 \quad (3)$$

Interaction Between Process Parameter and FMAB – Workpiece Contact Temperature

Interaction Between FMAB-Speed and Workpiece-FMAB Gap On Contact Temperature

Figure 3 (a–b) shows that at a low workpiece-FMAB gap, i.e., $X_2 = 6$ mm, the rise in speed of FMAB increases the temperature of contact between FMAB and the workpiece specimen during the finishing operation.

The same trend is seen at a higher workpiece-FMAB gap, i.e., $X_2 = 7$ mm, with a decreased value of temperature contact. The reason can be that a low workpiece-FMAB gap results in increased friction between FMAB and the work specimen, which increases the contact temperature. A higher workpiece-FMAB gap results in reduced friction, which correspondingly decreases the contact temperature.

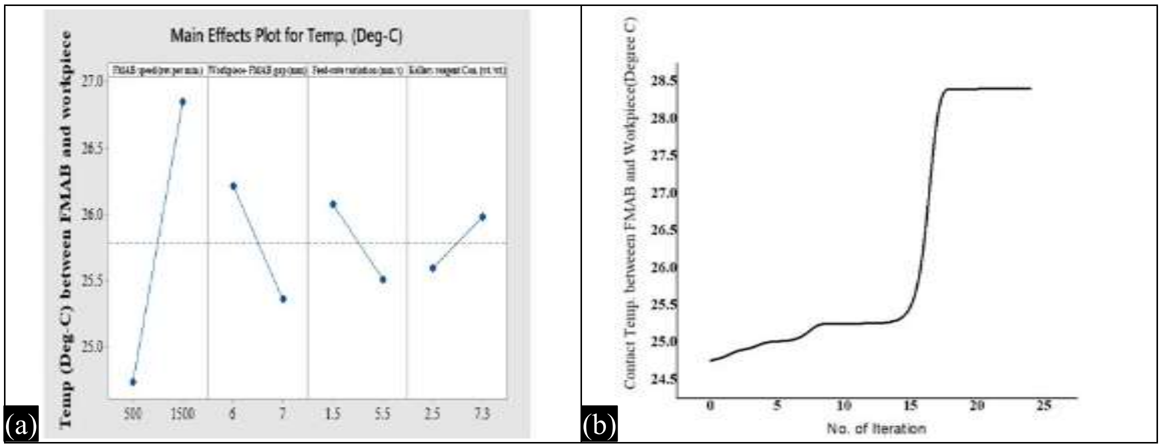
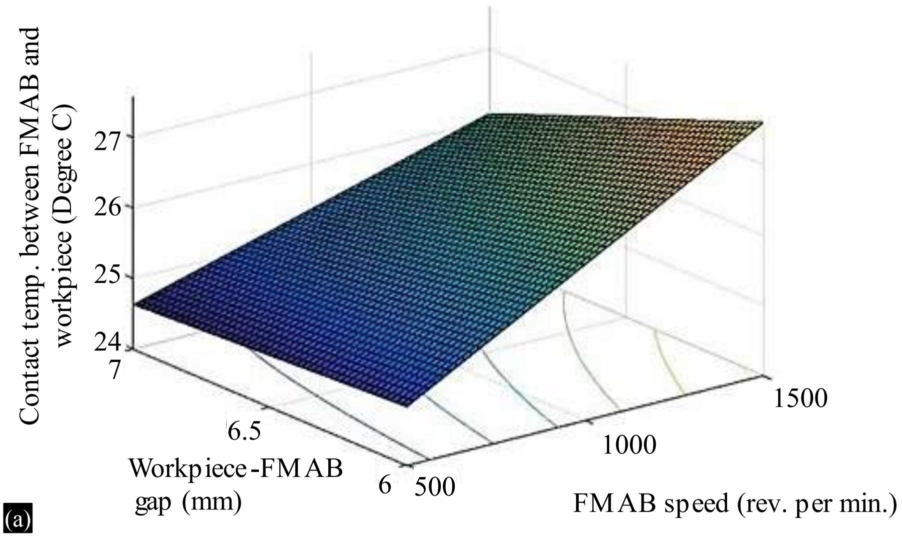


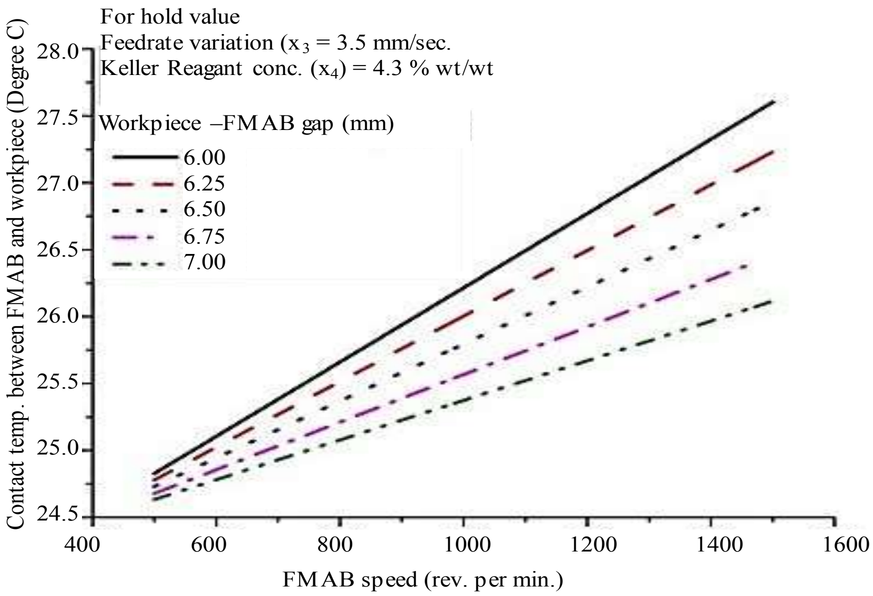
Figure 2. Main effect plot and result obtained by optimization process

Table 4. Validation of theoretical and experimental results of contact temperature between FMAB and aluminium alloy at optimum experimental process parameters.

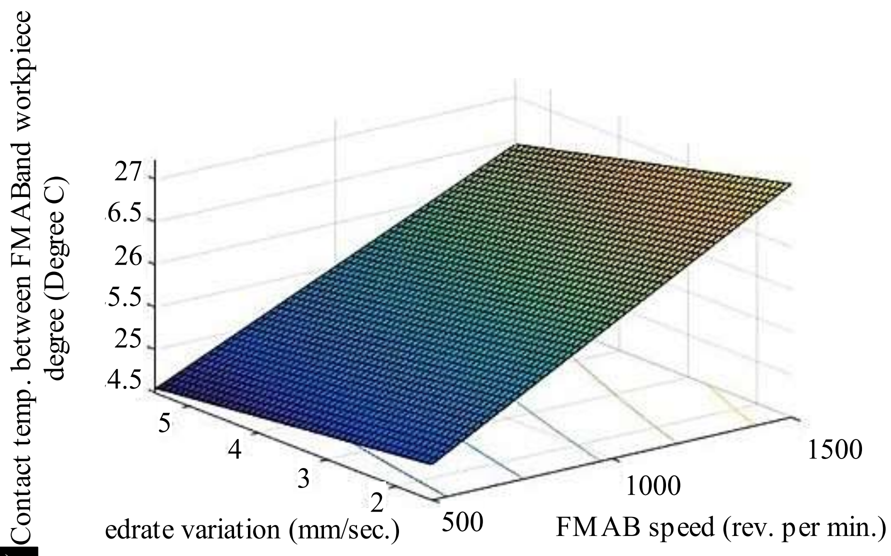
FMAB-speed (X_1) in rpm	Working-Gap (X_2) in mm	Feed- rate open rate(X_3) in mm/s	Conc. of etchant (X_4) −% wt/wt	Contact temperature between FMAB and aluminium alloy (ºC) from model equation	Investigational Contact temperature between FMAB and aluminium alloy (ºC)
1500	6	1.5	7.3	28.41±0.22	28.63


Contact temp. between FMAB and workpiece (Degree C)
27
26
25
24
7
6.5
6
Workpiece-FMAB gap (mm)
500
1000
1500
FMAB speed (rev. per min.)

(a)


For hold value
Feedrate variation (x3 = 3.5 mm/sec.
Keller Reagant conc. (x4) = 4.3 % wt/wt
Workpiece –FMAB gap (mm)
6.00
6.25
6.50
6.75
7.00
Contact temp. between FMAB and workpiece (Degree C)
28.0
27.5
27.0
26.5
26.0
25.5
25.0
24.5
400
600
800
1000
1200
1400
1600
FMAB speed (rev. per min.)

(b)


Contact temp. between FMABand workpiece degree (Degree C)
27
6.5
26
5.5
25
4.5
5
4
3
2
edrate variation (mm/sec.)
500
1000
1500
FMAB speed (rev. per min.)

(c)

Journal of Polymer & Composites
Volume 14, Special Issue 1
ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

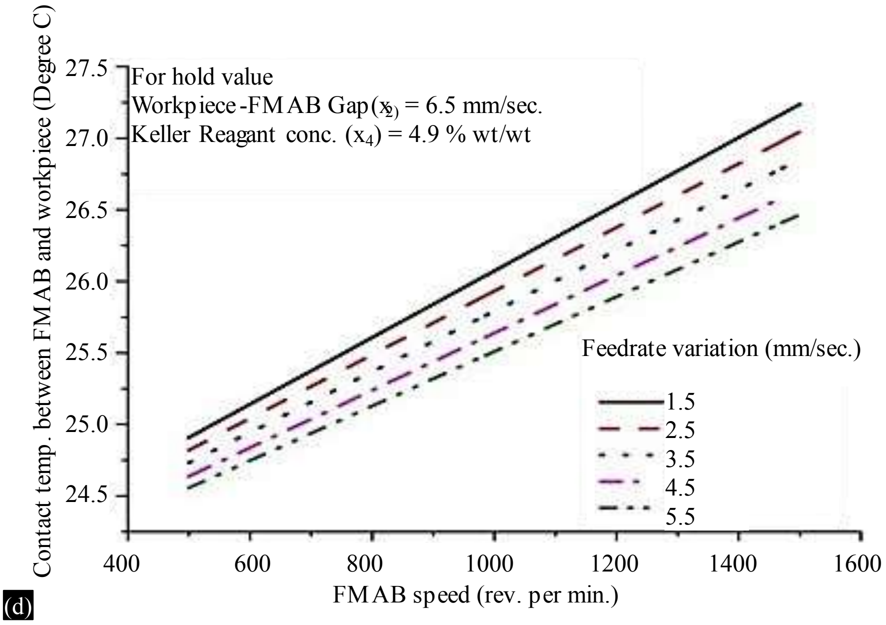


Figure 3. Interaction between (a, b) FMAB speed and workpiece FMAB gap (c, d) FMAB speed and feed rate variation.

Interaction Between FMAB-Speed and Feed-Rate Variation of Workpiece on Contact Temperature

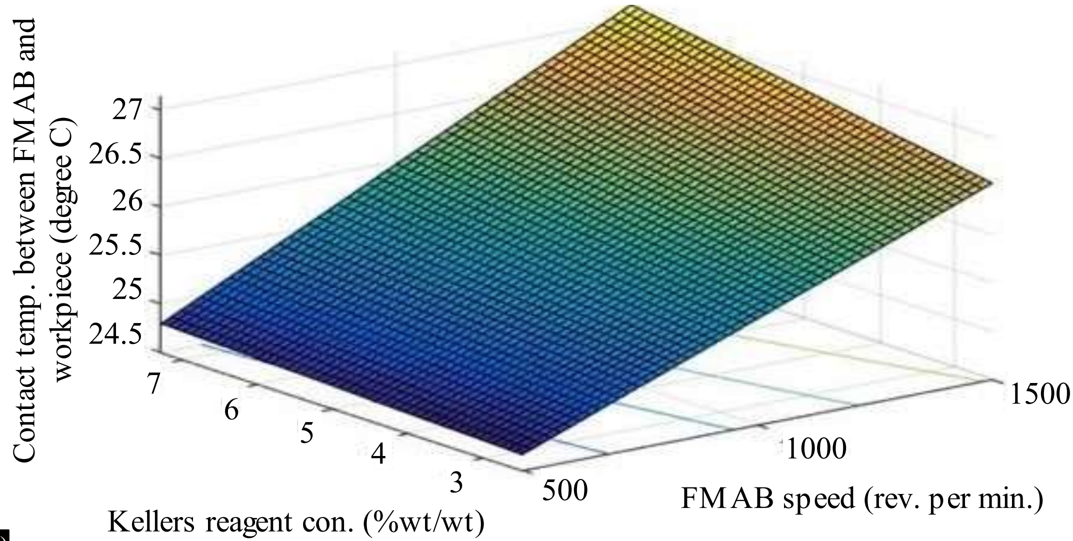
Figures 3(c, d) shows that at a low value of Feed-rate variation (X_3 = 1.5 mm/s) and a higher value of FMAB speed (X_1 = 1500 rpm), the contact temperature is found to have a value on the larger scale, and an increasing trend is found. The same trend can be seen at a higher value of feed rate variation (X_3 = 5.5 mm/s) and a higher value of FMAB speed (X_1 = 1500 rpm), but the contact temperature is found to be on the reduced side. The possible reason for such variation could be that the lesser the feed rate variation of the workpiece, the higher the contact duration of FMAB and the work specimen and the greater the contact temperature generated at the interface.

Interaction Between FMAB Speed and Concentration of Keller's Reagent on Contact Temperature

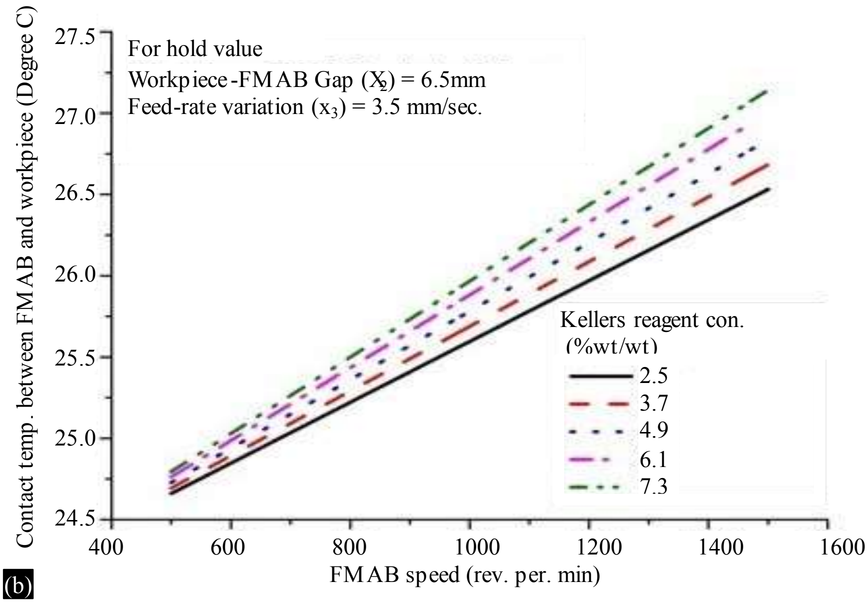
Figures 4(a, b) illustrates the interaction between FMAB speed and Keller's reagent concentration on contact temperature at the FMAB-work specimen interface. Higher FMAB speed (1500 rpm) and reagent concentration (7.3% wt./wt.) result in increased temperature. A lower concentration (2.5% wt./wt.) reduces oxidation, leading to fewer atomic collisions and lower temperatures. Conversely, higher concentration accelerates oxidation, decreasing molecular distance and increasing atomic collisions, raising the temperature. Regardless of FMAB speed, an increase raises contact temperature. The etching effect of Keller's reagent on aluminium alloy further influences oxidation rates, with lower concentrations minimizing oxidation and higher concentrations increasing it, thereby influencing overall interface temperature.

Interaction between Workpiece-FMAB gap and Feed-rate variation of workpiece on contact temperature

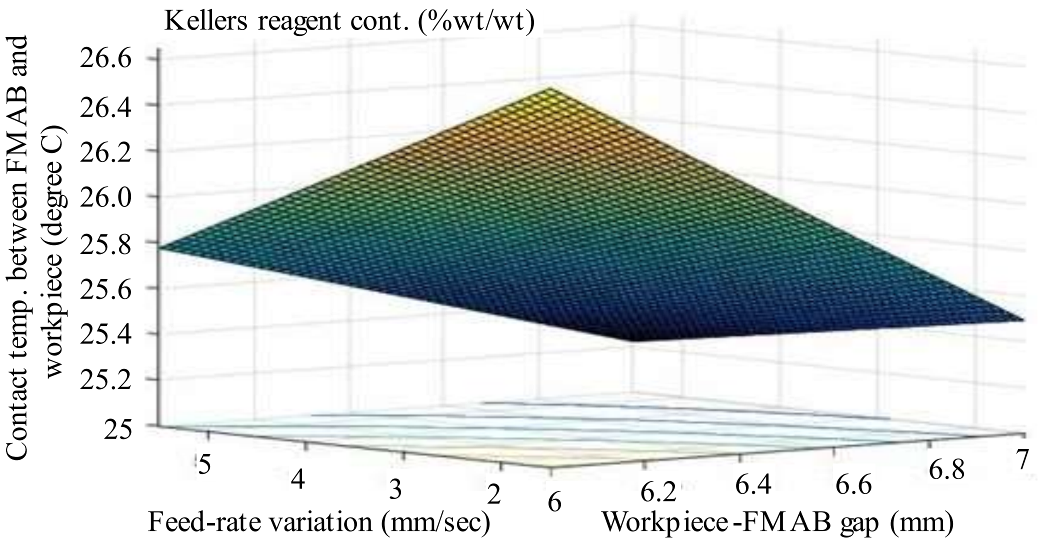
Figures 4(c, d) shows the interaction between Workpiece-FMAB gap and Feed-rate variation of workpiece on contact temperature. A growth in the gap of workpiece-FMAB with superior feed-rate variation (1.5–5.5 mm/s) decreases interaction temperature due to weaker magnetic alignment and reduced abrasive contact. A low gap (X_2=6 mm) and low feed rate (X_3=1.5 mm/s) result in higher temperatures, while a high gap (X_2=7 mm) and high feed rate (X_3=5.5 mm/s) result in lower temperatures. The weak magnetic field at larger gaps disrupts FMAB chain alignment, reducing abrasive contact and lowering interaction temperature.


Contact temp. between FMAB and workpiece (degree C)
27
26.5
26
25.5
25
24.5
7
6
5
4
3
Kellers reagent con. (%wt/wt)
500
1000
1500
FMAB speed (rev. per min.)

(a)


For hold value
Workpiece-FMAB Gap (X_2) = 6.5mm
Feed-rate variation (x_3) = 3.5 mm/sec.
Kellers reagent con. (%wt/wt)
2.5
3.7
4.9
6.1
7.3
Contact temp. between FMAB and workpiece (Degree C)
27.5
27.0
26.5
26.0
25.5
25.0
24.5
400
600
800
1000
1200
1400
1600
FMAB speed (rev. per. min)

(b)


Kellers reagent cont. (%wt/wt)
Contact temp. between FMAB and workpiece (degree C)
26.6
26.4
26.2
26.0
25.8
25.6
25.4
25.2
25
5
4
3
2
Feed-rate variation (mm/sec)
6
6.2
6.4
6.6
6.8
7
Workpiece-FMAB gap (mm)

(c)

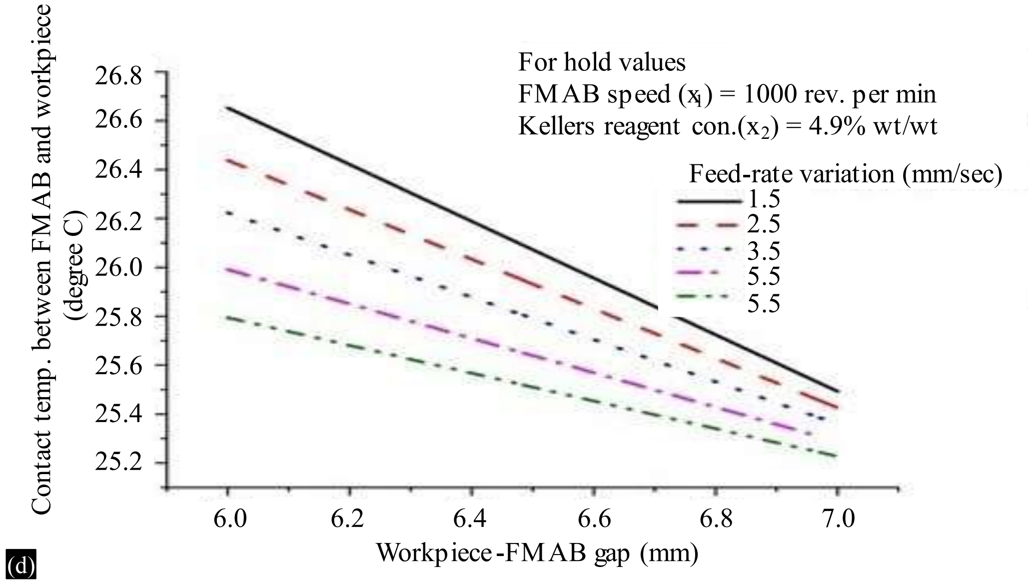


Figure 4. Interaction between (a, b) FMAB Speed and Keller's Reagent concentration. (c, d) Workpiece FMAB gap and feed rate variation.

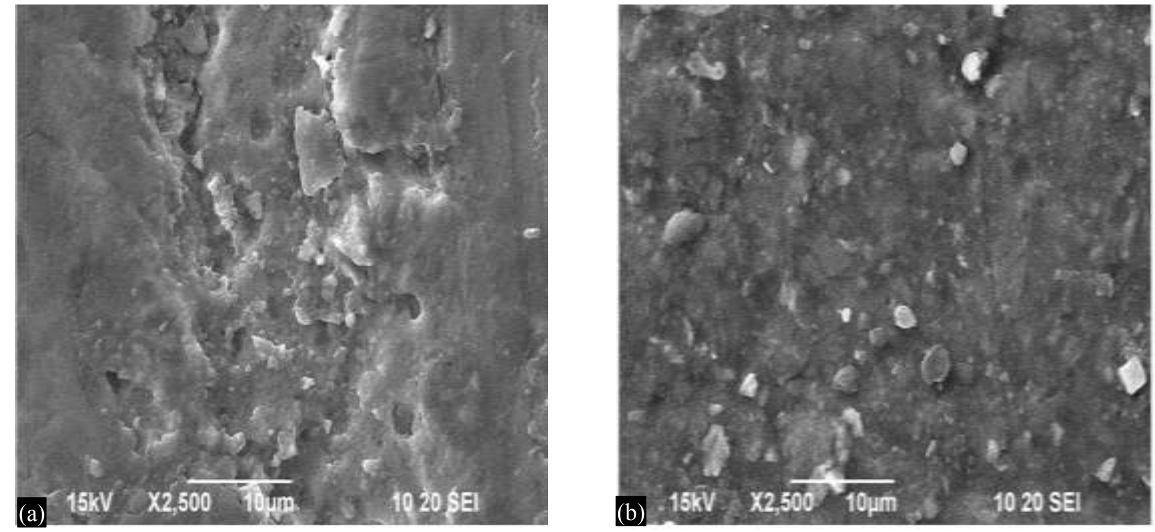


Figure 5. SEM Images of (a) Unpolished Aluminium 6061 Alloy, (b) Polished Aluminium 6061 Alloy at Optimum Parameters.

ANALYSIS OF SURFACE ASPERITY WITH SEM IMAGES

The unpolished SEM micrograph shown in Figure 5(a) has a rough, irregular surface with asserted asperities, weak debris, and broken oxide layers. This morphology shows no prior thermal influence, as the surface has not undergone frictional heating or mechanical pressing. The heat spreading across this surface is non-uniform but normally little, as no polishing-induced heat exists. The polished SEM micrograph in Figure 5(b) shows a much more uneven and more homogenized surface, and this morphology directly associates with heat generation during polishing. Higher temperatures in the polished region encourage concentrated annealing, relieving micro-stresses. As a result, the polished image lacks the cracked debris noticeable in the unfinished surface. The overall homogeneity of the polished surface indicates a more uniform temperature distribution during the polishing operation. A more consistent thermal field leads to smoother asperity levelling and microstructural uniformity. The uniform smoothness implies that the polishing process generated a consistent and controlled temperature distribution, improving surface finish without affecting thermal damage. No facts of melting, flow lines, or thermal pits are detected, indicating that the temperature stayed below aluminium's critical softening/melting limit.

CONCLUSIONS

These conclusions help optimize the MAF process to improve machining efficiency and surface integrity.

1. Raising the FMAB speed elevates the contact temperature because of the increased friction between the abrasive particles and the workpiece surface.
2. A lowered gap between the FMAB and the workpiece produces higher temperatures due to increased frictional contact, whereas a larger gap helps lower the temperature.
3. Lower feed rates cause the FMAB to remain in contact with the workpiece for a longer duration, resulting in higher temperatures; in contrast, higher feed rates reduce the heat generated.
4. Lower concentrations of Keller's reagent produce comparatively lower temperatures as oxidation is limited, while higher concentrations raise the temperature owing to enhanced oxidation and increased molecular interactions.
5. The most favourable parameters for obtaining the lowest contact temperature were found to be an FMAB speed of 1500 RPM, a working gap of 6 mm, a feed rate of 1.5 mm/s, and 7.3% wt./wt. Keller's reagent concentration, yielding a minimum temperature of 28.41°C.

REFERENCES

1. Hou ZB, Komanduri R. Magnetic field assisted finishing of ceramics—Part III: On the thermal aspects of magnetic abrasive finishing (MAF) of ceramic rollers. J Tribol. 1998;120(4):660–667. doi:10.1115/1.2833763
2. Davies MA, Ueda T, M'saoubi R, Mullany B, Cooke AL. On the measurement of temperature in material removal processes. CIRP Ann Manuf Technol. 2007;56(2):581–604. doi:10.1016/j.cirp.2007.10.009
3. Shen B, Xiao G, Guo C, Malkin S, Shih AJ. Thermocouple fixation method for grinding temperature measurement. doi:10.1115/1.2976142
4. Kumar G, Yadav V. Temperature distribution in the workpiece due to plane magnetic abrasive finishing using FEM. Int J Adv Manuf Technol. 2009;41(11–12):1051–1058. doi:10.1007/s00170-008-1557-7
5. Mulik RS, Pandey PM. Mechanism of surface finishing in ultrasonic-assisted magnetic abrasive finishing process. Mater Manuf Process. 2010;25(12):1418–1427. doi:10.1080/10426914.2010.499580
6. Mulik RS, Pandey PM. Ultrasonic-assisted magnetic abrasive finishing of hardened AISI 52100 steels using unbonded SiC abrasives. Int J Refract Met Hard Mater. 2011;29(1):68–77. doi:10.1016/j.ijrmhm.2010.08.002
7. Mulik RS, Srivastava V, Pandey PM. Experimental investigations and modelling of temperature in the work-brush interface during ultrasonic-assisted magnetic abrasive finishing process. Mater Manuf Process. 2012;27(1):1–9. doi:10.1080/10426914.2010.515647
8. Kim H, Altan T. Effects of surface finish and die temperature on friction and lubrication in forging. Procedia Eng. 2014;81:1848–1853. doi:10.1016/j.proeng.2014.10.244
9. Kanish TC, Kuppan P, Narayanan S, Ashok SD. A fuzzy logic-based model to predict the improvement in surface roughness in magnetic field-assisted abrasive finishing. Procedia Eng. 2014;97:1948–1956. doi:10.1016/j.proeng.2014.12.349
10. Mishra V, Goel H, Mulik RS, Pandey PM. Determining work-brush interface temperature in the magnetic abrasive finishing process. J Manuf Process. 2014;16(2):248–256. doi:10.1016/j.jmapro.2013.10.004
11. Khajehzadeh M, Razfar MR, Akhlaghi M. Experimental investigation of tool temperature during ultrasonically assisted turning of aerospace aluminium. Mater Manuf Process. 2014;29(11–12):1453–1460. doi:10.1080/10426914.2014.930962

12. Wang H, Chen Y. The effect of finish rolling temperature on the microstructure and properties of non-quenched and tempered bainite steel. Procedia Eng. 2017;207:1839–1843. doi:10.1016/j.proeng.2017.10.948
13. Singh RK, Gangwar S, Singh DK. Experimental investigation on temperature-affected magnetic abrasive finishing of aluminium 6060. Mater Manuf Process. 2019;34(11):1274–1285. doi:10.1080/10426914.2019.1628263
14. Singh RK, Gangwar S, Singh DK. On the temperature analysis of magnetic abrasive finishing of aluminium 6060 using the finite element method. Mach Sci Technol. 2020;25(2):177–208. doi:10.1080/10910344.2020.1815036