APPENDIX - I
APPENDIX – IA
MATLAB program to measure flank wear

clc;
clearall;
closeall;

% ip_RGB = imread('2nd feed.JPG');
% ip_gray = rgb2gray(ip_RGB);
% figure,imagesc(ip_gray),colormap('gray'),title('Second Feed');
z = 1;% input('enter image number between 1 to 19:');
% q = imread(sprintf('C:\Users\ADMIN\Desktop\Desktop\Kalandar\Images\l
% (%d).bmp', z));
ip1_RGB = imread(sprintf('Images\l (Yd).jpg1',z));
ip1_gray = rgb2gray(ip1_RGB);
figure,imagesc(ip1_gray),colormap('gray'),title('First Feed');
% diff = ip_gray - ip1_gray;
edge1 = edge(ip1_gray,'canny');
figure,imagesc(edge1),colormap('gray'),title('First Feed Edge');
[h1,v1] = allign_img(z);
for i = 400 : 550
for j = 500 : 650
if(ip1_gray(i,j) > 220)
op(i,j) = 1;
else

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op(i,j) = 0;
end
end
op2(i,j) = 0;
end

figure,imagesc(op),colormap('gray'),title('First Feed op');
for j = 500:650
op1(j) = sum(op(:,j));
end
max_diff = max(max(op1));
edge2 = edge(op,'canny');
figure,imagesc(edge2),colormap('gray'),title('First Feed Edge');
for j = 500:650
count = 0;
maxcount(j) = 0;
for i = 400:550
if(op(i,j) == 1)
if(op(i-1,j) == 0)
count = 1;
xy = i;
else
count = count + 1;
end
else
  if pixel value is zero
    if(op(i-1,j) == 1)
      if(maxcount(j) < count)
        maxcount(j) = count;
        max_col(j) = j;
        max_row(j) = xy;
      end
    end
  end
end

% finding the best location with maximum deviation
val = 0;
abscissa = 0;
for j = 500 : 650
  if(val < maxcount(j))
    val = maxcount(j);
    abscissa = j;
    ordinate = max_row(abscissa);
  end
end

[ht1 wd1] = size(ip1_gray);
img_ht = 65;
ct_edge = (img_ht/ht1)*val ;

horz_l = ordinate - h1 ;%round(rand(1)*5) ;

vert_l = abscissa + val - v1 ;%round(rand(1)*22) ;

x1 = (ordinate/wd1) * 75 ;

y1 = (abscissa/ht1) * 65 ;

x2 = (horz_l/wd1) * 75 ;

y2 = (vert_l/ht1) * 65 ;

diff_x = abs(x1 - x2) ;

diff_y = abs(y1 - y2) ;

cp_points(1,1) = abscissa ;

cp_points(1,2) = ordinate ;

cp_points(2,1) = abscissa + v1 ;

cp_points(2,2) = ordinate + h1 ;
APPENDIX – 1B

GA programs for identification of optimal parameters combination

(i) Program for varying depth of cut

function y = two_min (x)
for x = (0.2 : 1.2);
if x >= 0.2;
y = 1.202 - 0.98653 * x - 0.0387 * x^2;
else y = 100000
if x <=1.2;
y = 1.202 - 0.98653 * x - 0.0387 * x^2;
else y = 100000
end
end
end

(ii) Program for varying feed

function y = two_min (x)
% for x = (180 : 500);
if x >= 180;
y = 1.9395 - 0.005686 * x + 0.000006 * x^2;
else y = 100000
if x <=500;
y = 1.9395 - 0.005686 * x + 0.000006 * x^2;
else y = 100000
end
end
end
else y = 100000
end
end
end

(iii) Program for varying speed

function y = two_min (x)

%for x = (355 : 1120);

if x >= 355;
    y = 1.5544 - 0.005107 * x + 0.000007 * x^2 ;
else y = 100000
if x <=1120;
    y = 1.5544 - 0.005107 * x + 0.000007 * x^2 ;
else y = 100000
end
end
end
APPENDIX – IC

AIA programs for identification of optimal parameters combination

(i) Program used for varying depth of cut

cle;
clearall;
closeall;

% for generating integer and fraction parts separately and converting to

% Binary values
% str1 = randi([0.2 1.2],1,10);
% str2 = randi([2 9],1,10)/10;
% for i = 1 : 10
%    str2_bin(i,:) = Fract(str2(i));
% end
% str = str1 + str2;
% % str = str1;

% str_bin = dec2bin(str1,1);
str = randi([2 12],1,10)/10;

% For generating decimal values without converting to binary
% str = randi(3199,1,10)/100;
for iter = 1 : 1

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pos = round(9 * rand(1,2));

x = min(pos);

y = max(pos);

while((x == y) | (x == 0))
    pos = round(9 * rand(1,2));
    x = min(pos);
    y = max(pos);
end

FWx=zeros(1,10);

for i = 1:1:10
    k = str(i);

    % FWx(i)=-12*k^5 + 975*k^4 - 28000*k^3 + 345000*k^2 - 1800000*k;
    % FWx(i) = 11.2418 + 2.939* k;
    FWx(i) = 1.202 - 0.98653 * k - 0.0387 * k^2;
end

FWx_1 = abs(round(10^2./FWx));

% sort_FWx = sort(FWx_1);

FWx_2 = FWx_1;

for i = 1:10
    [min1 pos1] = min(FWx_2);
    sort_FWx(i) = FWx_2(pos1);
    sort_str(i) = str(pos1);
    FWx_2(pos1) = 999999;
end
end

% str1 = str ;

for i = 1 : 10
    j = 1 ;
    while(j <= sort_FWx(i))
        l1 = x ;
        l2 = y ;
        ip = str(i) ;
        xnew(i,j) = Mut1(l1,l2,ip);
        k = xnew(i,j) ;
        % FWx2(i,j) = -12*k^5 + 975*k^4 - 28000*k^3 + 345000*k^2 - 1800000*k;
        % FWx2(i,j) = 11.2418 + 2.939*k ;
        FWx2(i,j) = 1.202 - 0.98653 * k - 0.0387 * k^2;
        kk(i,j) = k ;
        % generating x y values
        pos = round( 9 * rand(1,2)) ;
        x = min(pos) ;
        y = max(pos) ;
        while((x == y) | (x == 0))
            pos = round( 9 * rand(1,2)) ;
            x = min(pos) ;
            y = max(pos) ;
        end
j = j + 1 ;
end

% localmin(i) = min(min(FWx2(i,:),FWx(i)));
end
end

% localmin(i) = min(min(FWx,FWx2));

gx = FWx';

for i1 = 1 : 10
    for j1 = 2 : 4
        gx(i1,j1) = FWx2(i1,j1-1);
    end
end

% min1 =

% Extra Code to remove the value below 350

kk1 = kk ;
gx1 = gx ;

for i1 = 1 : 10
    for j1 = 2 : 3
        if(kk(i1,j1)<0.2)
            kk1(i1,j1) = 9999 ;
gx1(i1,j1) = 9999 ;
        end
    end
end
end

% Extra code ended

for i1 = 1 : 10
    min1 = 999999 ;
    for j1 = 2 : 3
        if(min1 > gx1(i1,j1))
            localmin(i1) = gx1(i1,j1) ;
            ipos(i1) = i1 ;
            jpos(i1) = j1 ;
            min1 = gx1(i1,j1) ;
        end
    end
end

end

globalmin = 999999 ;

for i1 = 1 : 10
    if(globalmin > localmin(i1))
        globalmin = localmin(i1) ;
        pos_i = ipos(i1) ;
        pos_j = jpos(i1) ;
    end
end

ip_val = kk1(pos_i,pos_j)
globalmin
(ii) Program for varying feed

clc;
clearall;
closeall;

% for generating integer and fraction parts separately and converting to
% Binary values

str1 = randi([180 500],1,10);

% str2 = randi(99,1,10)/100;
% for i = 1:10
% str2_bin(i,:) = Fract(str2(i));
% end

% str = str1 + str2;
str = str1;

str_bin = dec2bin(str1,11);

% For generating decimal values without converting to binary

% str = randi(3199,1,10)/100;

for iter = 1:100

pos = round( 11 * rand(1,2));

x = min(pos);

y = max(pos);

while((x == y) | (x == 0)) .
pos = round( 11 * rand(1,2));

x = min(pos);
y = max(pos);

end

FWx=zeros(1,10);

for i = 1:1:10
k = str(i);

% FWx(i)=−12∗k^5 + 975∗k^4 - 28000∗k^3 + 345000∗k^2 - 1800000∗k;
% FWx(i) = 11.807 + 0.002724∗k;
% FWx(i) = 37.2426 + 0.00228∗k + 0.00004∗(k^2);
FWx(i) = 1.9395 - 0.005686 * k + 0.000006 * k^2;
end

FWx_1 = abs(round(10^0.5./FWx));

% sort_FWx = sort(FWx_1);

FWx_2 = FWx_1;

for i = 1:10
[min1 pos1] = min(FWx_2);

sort_FWx(i) = FWx_2(pos1);

sort_str(i) = str(pos1);

FWx_2(pos1) = 999999;
end

% str1 = str;

for i = 1:10
j = 1;

while(j <= sort_FWx(i))
\( \text{xnew}(i,j) = \text{Mut}(x,y,\text{str}(i)) ; \)

\( k = \text{xnew}(i,j) ; \)

\% FWx2(\(i,j\)) = -12*k^5 + 975*k^4 - 28000*k^3 + 345000*k^2 - 1800000*k ; \)

\% FWx2(\(i,j\)) = 11.807 + 0.002724*k ;

\% FWx2(\(i,j\)) = 37.2426 + 0.00228*k + 0.00004*(k^2) ;

FWx2(\(i,j\)) = 1.9395 - 0.005686 * k + 0.000006 * k^2 ;

\( \text{kk}(i,j) = k ; \)

\% generating x y values

pos = round( 11 * rand(1,2) ) ;

x = min(pos) ;

y = max(pos) ;

while((x == y) | (x == 0))

pos = round( 11 * rand(1,2) ) ;

x = min(pos) ;

y = max(pos) ;

end

j = j + 1 ;

end

\% localmin(i) = min(min(FWx2(i,:),FWx(i))) ;

end

end

\% localmin(i) = min(min(FWx,FWx2)) ;

gx = FWx' ;
ip_val = str' 

for i1 = 1 : 10
    for j1 = 2 % :8
        gx(i1,j1) = FWx2(i1,j1-1) ;
        ip_val(i1,j1) = kk(i1,j1-1) ;
    end
end
%
Extra Code to remove the value

ip_val1 = ip_val ;
gx1 = gx ;
for i1 = 1 : 10
    for j1 = 2 % :8
        if(ip_val(i1,j1) > 500 )
            ip_val1(i1,j1) = 9999 ;
gx1(i1,j1) = 9999 ;
        end
    end
end
%
Extra code ended

for i1 = 1 : 10
    min1 = 9999999 ;
    for j1 = 2 % :7
        % if(gx(i1,j1) > 180)
if(min1 > gx1(i1,j1))
    localmin(i1) = gx1(i1,j1);
    ipos(i1) = i1;
    jpos(i1) = j1;
    min1 = gx1(i1,j1);
end
% end
end
end

globalmin = 999999;
for i1 = 1 : 10
    if(globalmin > localmin(i1))
        globalmin = localmin(i1);
        pos_i = ipos(i1);
        pos_j = jpos(i1);
    end
end

ipip_value = ip_val1(pos_i,pos_j)

globalmin

(iii) Program for varying speed

clc;

clearall;
closeall;
% for generating integer and fraction parts separately and converting to

% Binary values
str1 = randi([355 1130], 1, 10);
% str2 = randi(99, 1, 10)/100;
% for i = 1:10
%     str2_bin(i,:) = Fract(str2(i));
% end
% str = str1 + str2;
str = str1;
str_bin = dec2bin(str1, 11);
% For generating decimal values without converting to binary
% str = randi([3199, 1, 10]/100;
for iter = 1:100
    pos = round(11 * rand(1, 2));
    x = min(pos);
    y = max(pos);
    while((x == y) | (x == 0))
        pos = round(11 * rand(1, 2));
        x = min(pos);
        y = max(pos);
    end
FWx=zeros(1,10);

for i = 1:1:10
    k = str(i);

    % FWx(i)=-12*k^5 + 975*k^4 + 28000*k^3 + 345000*k^2 - 1800000*k;
    % FWx(i) = 11.807 + 0.002724*k;
    % FWx(i) = 37.2426 + 0.002284*k + 0.00004*(k^2);
    FWx(i) = 1.5544 - 0.005107 * k + 0.000007 * (k^2);
end

FWx_1 = abs(round(10^0.5./FWx)) ;

% sort_FWx = sort(FWx_1);

FWx_2 = FWx_1 ;

for i = 1:10
    [min1 pos1] = min(FWx_2) ;
    sort_FWx(i) = FWx_2(pos1) ;
    sort_str(i) = str(pos1) ;
    FWx_2(pos1) = 999999 ;
end

% str1 = str ;

for i = 1:10
    j = 1 ;

    while(j <= sort_FWx(i))
        xnew(i,j) = Mut(x,y,str(i));
        k = xnew(i,j) ;
    end
end
% $FWx2(i,j) = -12k^5 + 975k^4 - 28000k^3 + 345000k^2 - 1800000k$;

% $FWx2(i,j) = 11.807 + 0.002724k$;

% $FWx2(i,j) = 37.2426 + 0.00228k + 0.00004(k^2)$;

$FWx2(i,j) = 1.5544 - 0.005107k + 0.000007(k^2)$;

$k(i,j) = k$;

% generating x y values

pos = round(11 * rand(1,2));

x = min(pos);

y = max(pos);

while((x == y) | (x == 0))

pos = round(11 * rand(1,2));

x = min(pos);

y = max(pos);

end

j = j + 1;

end

% $localmin(i) = \min(\min(FWx2(i,:),FWx(i)))$;

end

end

% $localmin(i) = \min(\min(FWx,FWx2))$;

$gx = FWx'$;

ip_val = str';

for i1 = 1 : 10
for j1 = 2 :8
  gx(i1,j1) = FWx2(i1,j1-1);
  ip_val(i1,j1) = kk(i1,j1-1);
end
end

% Extra Code to remove the value
ip_val1 = ip_val;

gx1 = gx;

for i1 = 1 : 10
  for j1 = 2 :8
    if(ip_val(i1,j1) > 1130)
      ip_val1(i1,j1) = 9999;
      gx1(i1,j1) = 9999;
    end
  end
end
end

% Extra code ended
for i1 = 1 : 10
  min1 = 9999999;
  for j1 = 2 :7
    % if(gx(i1,j1) > 355)
    if(min1 > gx1(i1,j1))
      localmin(i1) = gx1(i1,j1);
    end
  end
end

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i(pos)(i1) = i1;

j(pos)(i1) = j1;

\text{min1} = \text{gxl}(i1,j1);

end

\% end

end

globalmin = 999999;

for i1 = 1 : 10

\text{if}(\text{globalmin} > \text{localmin}(i1))

\text{globalmin} = \text{localmin}(i1);

\text{pos_i} = \text{i(pos}(i1));

\text{pos_j} = \text{j(pos}(i1));

end

end

ipip_value = \text{ip_val1}(\text{pos_i},\text{pos_j})

global\text{min}
APPENDIX - II
APPENDIX- II

List of papers published based on this work


Optimization and Prediction of Parameters in Face Milling of Al-6061 Using Taguchi and ANN Approach

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Abstract

In this paper, Taguchi Method has been used to identify the optimal combination of influential factors in the milling process. Milling experiment has been performed on Al 6061 material, according to Taguchi orthogonal array (L₁₀₀) for various combinations of controllable parameters viz. speed, feed and depth of cut. The surface roughness (Rₐ) is measured and recorded for each experimental run and analyzed using Taguchi S/N ratios and the optimum controllable parameter combination is identified. An Artificial neural network (ANN) model has been developed and trained with full factorial design experimental data and a combination of control parameters have been found from ANN for the surface roughness (Rₐ) value, obtained from confirmation test, for the optimum control parameters which are obtained from Taguchi S/N ratios analysis. Taguchi method and ANN found different sets of optimal combinations but the confirmation test revealed that both got almost same Rₐ values.

Keywords: Controllable parameters, Al-6061, milling, Taguchi method, S/N ratio analysis, Artificial Neural Networks

1. INTRODUCTION

Roughness is often a good predictor of the performance of a mechanical component since irregularities in the surface may form nucleation sites for cracks or corrosion. Although roughness is usually undesirable, it is difficult and expensive to control during manufacturing. Decreasing roughness of a surface will usually exponentially increase its manufacturing costs. This often results in a trade-off between the manufacturing cost of a component and its performance in application. Increasing the productivity and the quality of the machined parts are the main challenges of metal-based industry. There has been increased interest in monitoring all aspects of the machining process. Quality of machining can be judged by surface roughness. Higher the surface finish quality will be the quality. Surface finish mainly depends on cutting speed, Depth of cut, Feed. Most of the operators use trial and error method to find the appropriate cutting condition.

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It is not the effective way to find out optimal cutting parameters. So the main objective of the study is to find the optimum parameters (speed, feed, depth of cut) so that surface roughness is optimized. Aluminium has much application in industries. Also automotive aircraft and train companies need to replace steel and cast iron with lighter metal like aluminium. So, it is important to know the machining behaviour of aluminium. There are various optimization techniques like Genetic Algorithm, Artificial Neural Network, Grey Analysis, Utility Concept, Response Surface Methods, Taguchi technique, Fuzzy Logic, etc. to find out optimum cutting conditions.

2. LITERATURE REVIEW

Şeref Aykut [1] developed an ANN model to predict the surface roughness of Castamide material after machining process. In the study, experiments on Castamide were done in CNC milling using high speed steel and hard metal carbide tools. Dr. Mike S. Lou et al. [2] developed a multi-regression model that can predict the surface roughness on the surface of the specimen (Al-6061) on which end milling operation has been carried out using a CNC machine. Surasit Rawangwong et al. [3] investigated the effects of cutting parameters on the surface roughness in semi-solid AA 7075 face milling. The results of the research could be applied in the manufacture of automotive components. Mathew A. Kuttolamadam et al. [4] studied the effects of machining feed on surface roughness in milling Al-6061. A controlled milling experiment on 6061 aluminium depicted the relationship between feed and surface quality. Yang Yang et al. [5] proposed a method based on gene expression programming (GEP) to construct the prediction model of surface roughness. GEP combines the advantages of the genetic algorithm (GA) and genetic programming (GP). Bharat chandra routara et al. [6] studied a multi-objective optimization problem by applying utility concept coupled with Taguchi method through a case study in CNC end milling of UNS C34000 medium leaded brass. The study aimed at evaluating the best process environment which could simultaneously satisfy multiple requirements of surface quality. B. Vijaya Krishna Teja et al. [7] conducted an experimental study on performance characteristics of AISI 304 stainless steel during CNC milling process. The work represents multi-objective optimization of milling process parameters using Grey-Taguchi method in machining of AISI 304 stainless steel. Sanjit Moshat et al. [8] studied the highlights of optimization of CNC end milling process parameters to provide good surface finish as well as high material removal rate (MRR).

In this paper, Taguchi method is adopted experimentally to investigate surface roughness influenced by the control parameters such as speed, feed and depth of cut. And also it presents an ANN approach for prediction of control parameters for surface roughness in face milling.

3. CONTROL PARAMETERS AND THEIR LEVELS

The parameters which influence the surface roughness of machined surface called control parameters such as speed, feed and depth of cut. In this work, three controllable parameters are considered and each parameter is set at four levels. The parameters and its levels are shown in Table 1.

<table>
<thead>
<tr>
<th>Table 1: control parameters and their levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Levels</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
</tbody>
</table>

4. EXPERIMENTAL DESIGN AND MILLING OF WORK MATERIAL

In this work, Taguchi L16 design is used for conducting milling experiments (see Fig.1) on Al6061 work material by considering different speed, feed and depth of cut combinations and the values of surface roughness are measured using Talysurf surface tester (Fig 2) recorded in Table 2. And also experiments are conducted for full factorial design (Table.6) to train the developed ANN.
Table 2: Experimental data of surface finish (Rz) is analyzed using Taguchi design in Minitab software and signal to noise (S/N) ratio values are determined. The optimum levels of influential parameters are determined based on the obtained S/N ratios.

5. OPTIMIZATION OF MACHINING PARAMETERS USING TAGUCHI S/N RATIO ANALYSIS

The Experimental data of surface finish (Rz) is analyzed using Taguchi design in Minitab software and signal to noise (S/N) ratio values are determined. The optimum levels of influential parameters are determined based on the obtained S/N ratios.
After determining the S/N ratio values (Table 3), the effect of each Machining parameter is separated based on S/N ratio at different levels and the values of S/N ratio for each level of the controllable parameters and the effect of parameter on response (Ra) in rank wise are summarized in Table-4. Basically, large S/N ratio means it is close to good quality, thus, a higher value of the S/N ratio is desirable. From the Table-3 and Fig.3 the cutting parameters with the best level are spindle speed at level-4, feed at level-4 and DOC at level-1. The optimal levels for the controllable parameters obtained from this methodology are verified by the conformation test, the surface roughness (Ra) value obtained for these optimum control parameters is 0.115 μm and as shown in Table-5.

### Table 3: S/N ratios

<table>
<thead>
<tr>
<th>Exp. run</th>
<th>Surface roughness (Ra, μm)</th>
<th>S/N for Ra</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.695</td>
<td>3.160</td>
</tr>
<tr>
<td>2</td>
<td>0.82</td>
<td>1.723</td>
</tr>
<tr>
<td>3</td>
<td>0.04</td>
<td>-0.340</td>
</tr>
<tr>
<td>4</td>
<td>1.13</td>
<td>-1.061</td>
</tr>
<tr>
<td>5</td>
<td>1.205</td>
<td>-1.619</td>
</tr>
<tr>
<td>6</td>
<td>0.7</td>
<td>3.098</td>
</tr>
<tr>
<td>7</td>
<td>0.33</td>
<td>9.629</td>
</tr>
<tr>
<td>8</td>
<td>0.535</td>
<td>5.432</td>
</tr>
<tr>
<td>9</td>
<td>0.745</td>
<td>2.556</td>
</tr>
<tr>
<td>10</td>
<td>0.62</td>
<td>4.152</td>
</tr>
<tr>
<td>11</td>
<td>0.53</td>
<td>5.514</td>
</tr>
<tr>
<td>12</td>
<td>0.485</td>
<td>6.285</td>
</tr>
<tr>
<td>13</td>
<td>0.59</td>
<td>4.582</td>
</tr>
<tr>
<td>14</td>
<td>0.605</td>
<td>4.364</td>
</tr>
<tr>
<td>15</td>
<td>0.355</td>
<td>8.995</td>
</tr>
<tr>
<td>16</td>
<td>0.115</td>
<td>18.786</td>
</tr>
</tbody>
</table>

### Table 4: S/N ratio for each level of control parameters

<table>
<thead>
<tr>
<th>Levels</th>
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<td>1</td>
<td>0.870</td>
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<td>2</td>
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<td>3.101</td>
<td>3.846</td>
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<td>3</td>
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<td>5.949</td>
<td>3.003</td>
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<td>4</td>
<td>9.182</td>
<td>7.360</td>
<td>4.186</td>
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<tr>
<td>Delta</td>
<td>3.311</td>
<td>5.190</td>
<td>4.636</td>
</tr>
</tbody>
</table>

### Table 5: optimum control parameters values for S/N ratio analysis

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Speed (rpm)</td>
<td>1800</td>
<td></td>
</tr>
<tr>
<td>Feed (mm/ min)</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>Depth of Cut (mm)</td>
<td>0.10</td>
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</tbody>
</table>

### 6. PREDICTION OF VALUES USING ANN

A three-layer feed-forward network with sigmoid hidden neurons and linear output neurons can fit multi-dimensional mapping problems arbitrarily well, given consistent data and enough neurons in its hidden layer. The network is trained with Levenberg-Marquardt back propagation algorithm (trainlm). The structure of artificial neural network with input and output parameters is shown in Fig. 4(a). Cutting speed, Feed rate and depth of cut are taken as the input parameters whereas surface roughness (Ra) is taken as output parameter.
As shown in Fig. 4, The ANN has three layers, input layer, hidden layer and output layer. The hidden layer consists of 10 neurons and the output layer consists of only one neuron. The experimental values of full factorial design (Table 6) are used for training (ref. Fig. 4) the network. A well trained ANN is well generalized which gives proper output for those input also which has never been encountered with the network while training. Training a network is nothing but to set optimum weights of the links of two neurons. These weights, activation function, number of layers and neurons in a layer decide how well nonlinearity can be defined. The performance plot and regression plots are shown in Figure 5 and 6 respectively. The best performance is obtained at epoch 6.
The confirmation test results for the optimal parametric combination obtained in Taguchi S/N ratio analysis is given as input to the trained ANN, and the network predicted the control parameter values as speed: 1800 rpm, feed: 250 mm/rev and depth of cut: 0.5 mm. Again confirmation test has been conducted for this parameter combination. The surface roughness ($R_s$) value obtained for these optimum control parameters is 0.113 μm (see Table 7).

### Table 6: Experiments for Full factorial design

<table>
<thead>
<tr>
<th>Run</th>
<th>Speed (rpm)</th>
<th>Feed (mm/rev)</th>
<th>DOC (mm)</th>
<th>$R_s$ (μm)</th>
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<tr>
<td>1</td>
<td>900</td>
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<td>2</td>
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<td>3</td>
<td>900</td>
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<td>0.852</td>
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<td>4</td>
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<td>5</td>
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<td>6</td>
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<td>7</td>
<td>900</td>
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<td>8</td>
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<td>10</td>
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<td>2.636</td>
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<td>16</td>
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<td>0.85</td>
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<td>17</td>
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<td>0.9</td>
<td>2.924</td>
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<td>18</td>
<td>900</td>
<td>125</td>
<td>0.95</td>
<td>3.068</td>
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### Table 7: Confirmation test results

<table>
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<tr>
<th>Combination of controllable parameters</th>
<th>$R_s$ (μm)</th>
</tr>
</thead>
<tbody>
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<td>Speed (rpm)</td>
<td>Feed (mm/rev)</td>
</tr>
<tr>
<td>ANN</td>
<td>1800</td>
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<td>Taguchi</td>
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</table>

### 7. CONCLUSION

Among the consider parameters, speed has the most influence on the surface finish of the work-piece. The trained ANN is able to predict the $R_s$ values with reasonable accuracy. Taguchi S/N ratio analysis and ANN are useful to find the optimum combination of parameters for getting a good surface finish.
REFERENCES


Exploration of mechanical behavior of Al_2O_3 reinforced aluminium metal matrix composites

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Keywords: Aluminium oxide reinforcement, Aluminium metal matrix composites, Stir casting, Mechanical behavior.

ABSTRACT
The present research has focused on mechanical behaviour of aluminium oxide reinforced aluminium metal matrix composites. Aluminium metal matrix composites are fabricated using stir casting process by varying the reinforcement percentage volumes between 0 and 10, with 30 μm particles size. To study the mechanical behaviour through the effect of weight percentage of aluminium oxide, the fabricated specimens are tested for the mechanical and physical properties such as tensile strength, hardness and density and these values are compared with theoretical values which are obtained through the rule of mixtures. The mechanical properties of the composites are found to be greatly influenced with increasing the percentage volume of the reinforcement. Also it was observed that the experimental values of mechanical behaviour of AMMCs are nearer to the theoretical values.

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Introduction
Now a day the modern automotive and aerospace industries are looking towards light weighted and high strength materials to increase their overall efficiency. As in present scenario the aluminium metal matrix composites will secure the requirements of such industries, due to their low weight, high strength, thermal resistance, and corrosion resistance properties. The reinforcements used in these composites, may be in the form of continuous or discontinuous fibers, whiskers, and particles.

The metal matrix composites can be produced either by melting process or powder metallurgy. Over the powder metallurgy, the melting process has a few imperative advantages such as healthier bonding between matrix and particles, easier control of MMC structure, and low cost of processing. Among the various types of MMCs, the aluminium metal matrix composites (AMMCs) have been increase their significances in various engineering applications such as cylinder block liners, vehicle drive shafts, automotive pistons, bicycle frames, etc. [12-16].

[1] Studied the salient features of experimental as well as analytical and computational characterization of the mechanical behaviour of MMCs. The main focus is on wrought particulate reinforced light alloy matrix systems, with a particular emphasis on tensile, creep, and fatigue behaviour. [2] Investigated the structure and mechanical properties of Al MMCs, fabricated by stir casting method. The influences of weight fraction of SiCp reinforcement on tensile strength and fracture toughness have been evaluated. [3] Compared the Powder Metallurgy method and the stir casting method for producing the AMMC through testing for mechanical properties and conclude the stir casting method is best suitable for preparation of AMMC. [4] Studied the metal matrix and ceramic matrix composites and their process technologies and applications. [5] Investigated the effect of heat treatment on the hardness, wear behaviour, and friction properties of Al 6061 composite reinforced with sub-micron Al_2O_3 (10% vol.) produced by powder metallurgy. [6] Developed the aluminium metal matrix composites reinforced with aluminium nitride by stir casting process, and investigated the morphology of the composite and particle distribution by optical microscopy. [7] Developed and studied the tensile properties of 6063/Al_2O_3 Particulate Metal Matrix Composites fabricated by Investment Casting Process. The yield strength and fracture strength increase with increase in volume fraction of Al_2O_3, whereas ductility decreases. The fracture mode is ductile in 10% volume fraction composite and the brittle fracture is observed in 20% and 30% volume fraction composites. [8] Investigated the mechanical properties like hardness and tensile strength and the wear resistance properties of Al6061/SiC and Al7075/Al_2O_3 composites prepared by using the liquid metallurgy technique. Reinforcement of the SiC and Al_2O_3 resulted in improving the hardness and density of their respective composites. [9] Developed Al/SiC MMC by investigating the mechanical properties of different metal matrix composites produced from Al6061, Al6003 and Al7072 alloy reinforced with silicon carbide particulates. The yield strength, ultimate strength, and ductility of Al/SiC metal matrix composites are in the descending order of Al6061, Al6003 and Al7072 matrix alloys. [10] Developed the aluminium metal matrix composites by different processing temperatures with different holding time to understand the influence of process parameters on the distribution of particle in the matrix and the resultant mechanical properties using the stir casting process. The distribution is examined by microstructure analysis, hardness distribution and density distribution. [11] Studied the preparation, microstructure and properties of Al7075/SiCp system produced by mechanical alloying.

The literature reveals that the little research is done on the mechanical behaviour of Al_2O_3 reinforced aluminium metal matrix composites. Hence, the present research is focused on experimental investigation to study the microstructural and mechanical behavior of Al6061/Al_2O_3 and Al70755/Al_2O_3 AMMCs.

Preparation of AMMCs
The aluminium alloys Al6061 and Al7075 are used as the matrix metal for the fabrication of the composites that has been reinforced with 2 wt. %, 4 wt. %, 6 wt. %, 8 wt. % and 10 wt. %
of Al2O3 of average 30 µm size. The chemical composition, mechanical and thermo physical properties of the matrix material (Al6061 and Al7075) and reinforcement material (Al2O3) are given in Tables 1 and 2. The composite was fabricated by the stir casting technique. The melt was casted in a stir casting furnace in a range of 750±20°C. A schematic view of the stir casting set up and metallic mold is shown in Fig.1. The melt has mechanically stirred by using a graphite stirrer with motor, during this the pre-heated aluminium oxide particles (about 800°C to make their surfaces oxidized) and 1% of magnesium as a wetting agent (to reduce the surface tension of aluminum and to increase the wetting property between matrix and reinforcement material) were added gradually into the molten metal. The stirring process is carried out at a temperature of 750°C with a stirring speed 600 rpm and time of 10min. One K-type thermocouple has inserted into the graphite crucible to measure the temperature variation of the molten metal. Finally, the mechanical properties Al6061/ Al2O3 and Al7075/ Al2O3 composites are compared with the unreinforced Al6061 and Al7075 matrix alloys. The micro structural characteristics, tensile strength, hardness and density of the composites are evaluated.

Figure 1 Experimental Setup

Table 1. Chemical Composition of Al6061 and Al7075 by weight percentage

<table>
<thead>
<tr>
<th>Elements</th>
<th>Si</th>
<th>Fe</th>
<th>Cu</th>
<th>Mn</th>
<th>Mg</th>
<th>Cr</th>
<th>Zn</th>
<th>Ti</th>
<th>Al</th>
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<tbody>
<tr>
<td>Al6061</td>
<td>0.62</td>
<td>0.23</td>
<td>0.22</td>
<td>0.25</td>
<td>0.04</td>
<td>0.22</td>
<td>0.10</td>
<td>0.1</td>
<td>Balance</td>
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<tr>
<td>Al7075</td>
<td>0.4</td>
<td>0.5</td>
<td>1.0</td>
<td>0.5</td>
<td>3.0</td>
<td>0.15</td>
<td>5.5</td>
<td>0.2</td>
<td>Balance</td>
</tr>
</tbody>
</table>

Table 2. Mechanical and thermo physical properties of Al6061, Al7075 and Al2O3

<table>
<thead>
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<th>Properties</th>
<th>Al6061</th>
<th>Al7075</th>
<th>Al2O3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elastic Modulus (Gpa)</td>
<td>70-80</td>
<td>70-80</td>
<td>500</td>
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<tr>
<td>Density (g/cm³)</td>
<td>2.7</td>
<td>2.81</td>
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<td>Poisson’s Ratio</td>
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<td>0.21</td>
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<tr>
<td>Hardness (HBS/300)</td>
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<td>60</td>
<td>1175</td>
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<tr>
<td>Tensile Strength (MPa)</td>
<td>115(T)</td>
<td>220(T)</td>
<td>282.55(T)</td>
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<tr>
<td>Compressive strength (C)</td>
<td>15(T)</td>
<td>220(T)</td>
<td>282.55(T)</td>
</tr>
<tr>
<td>Average particle size (Mesh)</td>
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<td>400</td>
<td></td>
</tr>
<tr>
<td>Thermal conductivity (W/m K)</td>
<td>167</td>
<td>130</td>
<td>100</td>
</tr>
<tr>
<td>Liquidus temperature (°C)</td>
<td>652</td>
<td>635</td>
<td>2072</td>
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</table>

Exploration of Mechanical Properties

The composite specimens are evaluated for Tensile strength, Hardness and Density by theoretical (Rule of Mixture) and Experimental methods.

Tensile Strength

Theoretical values of tensile strength are obtained by Rule of Mixture (Eq.1) and experimental values are obtained by conducting experiments using the computer interfaced universal testing machine on AMMC samples which are machined as per ASTM D 3039-76 specifications (Fig.2). From the Table 3&4 and Fig.3 the experimental result shows that the tensile strength of the produced AMMCs is somewhat higher than that of the non reinforced Aluminum alloys. It can be noted that the addition of aluminum oxide particles (Al2O3) enhanced the tensile strength of the composites. It is apparent that an increase in the weight percentage of aluminum oxide particle results in an increase in the tensile strength. The tensile strength of Al 6061 and Al 7075 in non-reinforced condition is 115 and 220 MPa and this value increases to a maximum of 130.89 and 226.1 MPa for Al 6061/ Al2O3/10 wt. % and Al 7075/Al2O3/10 wt. %.

\[ \sigma_t = \sigma_{r1} + \sigma_{r2} + \sigma_{v} \]  

(1)

Where \( \sigma_t \), \( \sigma_{r1} \), and \( \sigma_{r2} \) are the tensile strength of composite, reinforcement and matrix materials and \( V_r \) and \( V_m \) are volume fractions of reinforcement and matrix materials.

Figure 2. Tensile tested specimen (a) Al6061-Al2O3 composite; (b) Al7075- Al2O3 composite

Figure 3. Experimental and Theoretical Tensile strength of Al6061-Al2O3 and Al7075- Al2O3 composites

Hardness

Hardness is one of the important mechanical properties in case of composite material as the hardness of matrix metal is very low, which limits its wide application. The hardness of matrix metal enhances due to reinforcement of Al2O3 particles with it. Hardness test has conducted on each AMMC specimen using ASTM E10-12 standards. These experimental values are compared with theoretical values of hardness obtained by the Eq.2 and shown in Table 3&4.

\[ H = H_r + V_m H_m \]  

(2)

Where \( H_r \), \( H_m \) and \( V_m \) are the Brinell hardness number of composite, reinforcement and matrix materials and \( V_r \) and \( V_m \) are volume fractions of reinforcement and matrix materials.

From Table 3&4 and Fig.4, the hardness value increases with the increase of weight percentage of Al2O3 particles. The maximum hardness value obtained at 10 wt. % of Al2O3.

Figure 4. Experimental and Theoretical Hardness of Al6061- Al2O3 and Al7075- Al2O3 composites
Density

Density is an important factor which is considered in material selection for several engineering applications to improve their efficiency. Theoretical values of density are obtained by the Eq.3 and the most common experimental method of density measurement simply involves dividing the object's mass by its volume. Hence to determine the experimental value of density, the AMMC samples of measured volume are weighed using a digital balance. From Table 3 & 4 and Fig.5 it can be observed that the density of the composite is higher than that of the matrix material. Also, the density of the composites increased with increase in filler content. Further, the theoretical and experimental density values are in line with each other. The increase in density of composites can be attributed to higher density of reinforcement particles.

\[ \rho_c = \rho_p \% p_r + \rho_m \% \rho_m \]  

where \( \rho_c \), \( \rho_p \), \( \rho_m \), \( p_r \) and \( \rho_m \% \) are the densities of composite, reinforcement and matrix materials and \( \rho_p \) and \( \rho_m \% \) are volume fractions of reinforcement and matrix materials.

![Figure 5. Experimental and Theoretical Density of Al6061-Al2O3 and Al7075-Al2O3 composites](image)

Optical micrographs of AMMCs

The mechanical properties of AMMCs are majorly influenced by the type of reinforcing particles and its distribution. It is necessary to distribute particles uniformly throughout the AMMC casting. The variable that directs the distribution of particles are solidification rate, fluidity, type of reinforcement and the method of casting process. The microstructures of the samples, cut from the casting at different locations are observed using optical microscope to study the particle distribution. The obtained optical micrograph (Fig.6 (a) & (b)) shows the uniform distribution of reinforcing particles. The particle distribution strongly influences the physical and mechanical properties of the composites.

![Figure 6 (a) Optical micrographs of Al6061 with 0 - 10% Al2O3; (b) Al7075 with 0 - 10% Al2O3](image)

Conclusions

The following conclusions have been drawn based on the experimental investigation on Al2O3 reinforced AMMCs at different weight fractions:

1. Tensile strength is enhanced with increase of reinforcement percentage in matrix.
2. The hardness of the composites is higher than the unreinforced matrix metal and the hardness of the cast composites increases linearly with increasing the weight fraction of Al2O3.
3. Density of the composites has been improved by increasing the percentage of the reinforcement. It is found that, an Al6061/Al2O3 composite have lower density than the Al7075/Al2O3 composites. So Al6061/Al2O3 composite can be used in applications where lower weight is desirable.
4. Microstructural observation shows that the Al2O3 particles are well distributed in matrix material and there is a good particular matrix interface bonding.

Scope of the future work

The study can also be extended by the addition of Al2O3 reinforce materials in aluminium composites other then Al6061 and Al7075. And also wear studies can be carried out.

Acknowledgments

The author would like to acknowledge Mr. G. Vijaya Kumar (Research scholar) and the staff of mechanical workshop of S. V. U. College of engineering, S.V. University Tirupati.

References

### Table 3. Mechanical properties of Al6061/Al2O3 composites

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<th>Al 6061/ Al2O30.2p</th>
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### Table 4. Mechanical properties of Al7975/Al2O3 composites

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<td>2.834</td>
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<td>2.86</td>
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Analysis on Multi Responses in Face Milling of AMMC Using Fuzzy-Taguchi Method

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Abstract

In this paper, Fuzzy-Taguchi Method has been used to identify the optimal combination of influential factors by analyzing the multi responses in the face milling. Milling experiment has been performed on AMMC (Aluminium Metal Matrix Composite), according to Taguchi orthogonal array (L27) for various combinations of influential parameters: speed, feed, depth of cut and coolant. Fuzzy logic is applied for the analysis of experimental response data of vibrations, temperature, surface roughness and resultant forces. The Fuzzy grade is calculated from this data and Fuzzy grade is optimized using Taguchi method in order to get the optimal parameter values, and also influence of parameters on individual responses is studied using Taguchi S/N ratio analysis. This work is useful for analysis of machining parameters in face milling.

Keywords

Face Milling, AMMC, Fuzzy Logic, Taguchi S/N Ratio Analysis

1. Introduction

Conventional materials have the limitations in achieving good combination of strength, stiffness, toughness, density, etc. To overcome these limitations and to meet the ever increasing demand of modern day technology, composites are most promising materials in recent days. Metal matrix composites (MMCs) possess high strength, hardness, toughness, and good thermal resistance properties as compared to unreinforced alloys.

Milling is the process of machining flat, curved or irregular surfaces by feeding the work piece against a rotating cutter containing a number of cutting edges. The literature review related to machining of AMMC is presented in the following.

*Corresponding author.

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Shivanand et al. (2004) [1] compared Powder Metallurgy method and stir casting method for producing the AMMC through testing of mechanical properties and concluded that stir casting method was best suitable for preparation of AMMC. Dalalah and Bataineh (2009) [2] presented a fuzzy logic approach to the selection of the best silicon crystal slicing technology. Fuzzy reasoning is used to model the expert’s comprehension and uncertainty in the factors used in the decision criteria. Kuttolamadom et al. (2010) [3] studied the effects of machining feed on surface roughness in milling Al-6061. Increase the feed up until a cut-off surface roughness limit is reached and then increase the speed within the roughness range, to maximize productivity. Yazdi and Khorram (2010) [4] investigated the selection of optimal machining parameters for face milling operations in order to minimize the surface roughness and to maximize the material removal rate using RSM and ANN methods. Abuthakeer et al. (2011) [5] carried out a study to obtain the surface roughness and vibration responses were investigated at various parametric levels and combinations using LabVIEW software. On the completion of the experimental test, ANN is used to validate the results. Gunay et al. (2011) [6] focused on studying of machining parameters on the cutting forces and surface roughness during face milling of Ti-6Al-4V alloy with carbide tools under dry conditions. Resultant cutting forces and surface roughness increased with an increase in feed rate, whereas decreasing with increase in cutting speed. Çalışkan et al. (2012) [7] showed the influence process parameters on the cutting forces (Fx, Fy, and Fz) and Ra in hard milling. According to the results of variance analysis, the cutting forces are the most sensitive to feed rate Fz and then depth of cut. The cutting speed is only influential on Fx. Globocki & Latica et al. (2013) [8] carried out Experimental Research Using of MQL in Metal Cutting. The analysis shows that turning with MQL is a good alternative for conventional lubrication. Al-Zubaidi et al. (2013) [9] proposed a new multi-objective optimization approach in the face milling. It is showed that the method provides a robust way of looking at the optimum parameter selection problems. Jatin (2013) [10] studied the effect of different machining on Surface Roughness in milling by Taguchi analysis. Low cutting speed should be used for long cutter life. High cutting speed and low feeds give best surface finishes. Venkata Ramaiah et al. (2013) [11] made an attempt to obtain optimum machining parameters for minimum cutting forces and cutting temperature by using Fuzzy Logic. It is showed that the method provides good results in machining of Al 6061. Das et al. (2014) [12] investigated the application of traditional Taguchi method with fuzzy logic for multi objective optimization of the machining process of Al-5Cu. Experimental results are demonstrated to present the effectiveness of this approach.

To address the lack of research in this issue, the present work has been done on face milling of AMMC with the following objectives:

1) To study the influence of machining parameters on multi responses;
2) To identify the optimal setting of milling process parameters (coolant, cutting speed, feed rate and depth of cut) for optimal responses: vibrations, temperature, surface roughness and resultant forces.

2. Taguchi Orthogonal Array for Conducting Experiments

In this experiment four process parameters at three levels have been considered are shown in Table 1.

L12 orthogonal array as shown in Table 2 has been chosen for conducting experiments. Experiments are performed according to this design and the values of surface roughness, resultant force, vibrations and temperature are recorded and their Normalized responses and response values are shown in Table 3.

3. Milling of AMMC Material

3.1. Experimental Procedure

Step by Step procedure used in the experimental work

1) Keep the milling machine ready for performing the machining operation;
2) Connect the DAQ system to milling machine;
3) Connect the milling tool dynamometer to the milling machine;
4) Prepare the AMMC work piece sample and fix in machine vice;
5) Fix the milling cutter to an arbor and make machine ready for experiment;
6) Perform milling experiments as per Taguchi design on work piece for various combinations of process control parameters like coolant, spindle speed, feed and depth of cut;
7) Measure surface roughness with the help of a portable stylus-type Talysurf (Taylor Hobson, mitutoyo);
8) Measure forces such as thrust force, feed force, cross feed force by using milling tool dynamometer;
9) Measure vibrations by using accelerometer sensor (PCB Accelerometer having Sensitivity 100.5 mV/g) and
temperature by using temperature sensor (NI-9211 Temperature Module) of LabVIEW based DAQ system.

3.2. Measurement of Responses

Experimental responses: surface roughness, vibrations, temperature and resultant forces are measured for different
combinations of influential parameters. The measuring instruments and procedure is presented in the following.

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</table>
3.2.1. Measurement of Surface Roughness
The surface roughness values of the machined surface are measured in order to analyze the surface finish quality. Surface Roughness is measured with the help of Talysurf (Figure 1).

3.2.2. Measurement of Vibrations Using PCB Accelerometer
Spindle vibrations are measured using LabVIEW based DAQ. To measure the vibrations of the spindle, PCB Accelerometer (sensitivity 100.5 mV/g) is placed on spindle as shown in Figure 2.

3.2.3. Measurement of Temperature Using NI-9211 Thermocouple
The temperature at the contact of tool and work piece is measured using LabVIEW software based NI-9211 temperature thermocouple. According to the design of experiments at various conditions Dry, Kerosene and soluble oil (Figure 3).

3.2.4. Measurement of Cutting Force Using Milling Tool Dynamometer
In order to measure the forces of thrust, feed and cross feed force, milling tool dynamometer (Figure 4) the resultant force [7] from these forces calculated.
3.3. Data Normalization

Data Normalization is done on data which has different range and unit in one data sequence may differ from the
Data preprocessing is also necessary when the directions of the target in the sequences are different.

If the target data value characteristic is "smaller the better". The original sequence can be normalized using the Equation (1) as follows:

\[
x'_i(k) = \frac{\text{max} x'_i(k) - x'_i(k)}{\text{max} x'_i(k) - \text{min} x'_i(k)}
\]

where \( i = 1, \ldots, m; \ k = 1, \ldots, n \). \( m \) is the number of experimental data items and \( n \) is the number of parameters. \( x'_i(k) \) denotes the original sequence, \( x'_i(k) \) the sequence after the data pre-processing, \( \text{max} x'_i(k) \) the largest value of \( x'_i(k) \), \( \text{min} x'_i(k) \) the smallest value of \( x'_i(k) \), and \( x' \) is the desired value.

4. Analysis of Multi Responses

Deals with analysis of multi responses data shown in Table 3 and optimization of process parameters in milling of AMMC using Fuzzy logic and Taguchi analysis. And also influence of process parameters on individual responses is studied using Taguchi S/N ratio analysis.


The experimental data is analyzed using Fuzzy logic to determine optimum process parameters as in the following.

4.1.1. Creation of Membership Functions

Figures 5-8 shows the membership function for vibrations, Temperatures, Surface roughness input values in the process parameter.

Figure 9 shows the membership function selected to defuzzify the output (performance), calculated using the simplifying rules. The rules for process parameter for some rules are shown in Table 4.

Using more than three fuzzy sets would cause an explosion in the number of possible expressions. For the current case study 3 fuzzy sets and 4 inputs are considered. This results in a possible 34 = 81 expressions. The five fuzzy sets used in the performance membership function are "very low", "low", "medium", "high", and "very high". Again, the trimf shape is employed to map the fuzzy sets. The use of the centroid defuzzification method.
is recommended as it results in a more smoothly shaped rule surface. In other words, the output performance index is less sensitive to slight variations in input values which occur near the fuzzy set overlaps. After the input and output membership functions are all defined and their fuzzy sets properly configured, the next step is to write the simplifying rules used to transform the input into output. As shown in the next section, this is the most crucial step in creating a fuzzy logic process parameter system.
4.1.2. Evaluation of Fuzzy Grade

Fuzzy grade values are determined from Fuzzy logic using Fuzzy rules (Table 4) and normalizing data (Table 3). By using evaluation function of the MATLAB editor.

The evaluation function is: \( b = \text{[experimental data]} \); \( a = \text{readfis ("File name"}, \ t = \text{evalfis}(b, a). \)

After executing above code, the output of FIS editor is obtained as shown in Table 5. These Fuzzy grade values are used for determining optimum parameter values by applying Taguchi techniques as in the following section.
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4.2. Taguchi Analysis

Taguchi S/N ratio analysis is performed on Fuzzy grade data shown in Table 6 using Minitab software and optimum parameter values are found (Table 7) and the main effects plot is shown in Figure 10. From the results (Table 7 and Figure 11), optimum process parameters combination for Fuzzy grade is Speed 3-Coolant 3-Depth of cut 3-Feed 1

Which means

Speed at level 3 (1400 rpm)

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<td>800</td>
<td>1.2</td>
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<td>1</td>
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<td>3</td>
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</table>

Delta 0.092 3.106 0.387 0.534
Coolant at level 3 (Soluble oil)
Depth of cut at level 3 (1.2 mm)
Feed at level 1 (315 mm/rev)

4.3. Individual Response Analysis

Taguchi S/N ratio analysis is applied for data shown in Table 5 to study the influence of process parameters on individual responses. The results are shown in Figures 11-14 and Tables 8-11.

4.3.1. S/N for Vibration versus Coolant, Speed, Feed and Depth of Cut

From Figure 11 and Table 8, the optimum process parameters combination for individual response (Vibration) is

- Speed 3
- Depth of cut 3
- Coolant 1, 2
- Feed 3

Which means:
- Speed at level 3 (1400 rpm)
- Depth of cut at level 3 (1.2 mm)
- Coolant at level 1, 2 (Dry, Kerosene)
- Feed at level 3 (800 mm/rev)
From Figure 12 and Table 9, the optimum process parameters combination for individual response (Temperature) is:

- Speed at level 3 (1400 rpm)
- Coolant at level 1 (Dry)
- Feed at level 3 (800 mm/rev)
- Depth of cut at level 3 (1.2 mm)

From Figure 13 and Table 10, the optimum process parameters combination for individual response (Resultant force) is:

- Speed at level 3
- Coolant at level 2
- Feed at level 3
- Depth of cut at level 3
Coolant at level 2 (Kerosene)
Feed at level 2 (500 mm/rev)
Depth of cut at level 3 (1.2 mm)

4.3.4. S/N for Surface Roughness versus Coolant, Speed, Feed and Depth of Cut

From Figure 14 and Table 11, the optimum process parameters combination for individual response (Surface roughness) is
Coolant3 - Depth of cut3 - Speed2 - Feed1
Which means
Coolant at level 3 (Soluble oil)
Depth of cut at level 3 (1.2 mm)
Speed at level 2 (1120 rpm)
Feed at level 1 (315 mm/rev)

4.4. Conformation Test Results

Conformation experiment is conducted for optimum parameter combination and the values of Vibrations (shown in Figure 15 and Figure 16), Temperature (shown in Figure 17 and Figure 18), surface roughness, and resultant forces are recorded (Table 12).

According to Fuzzy based Taguchi S/N ratio analysis, the optimal combination of input parameters is Coolant = Soluble oil
Speed = 1400 rpm
Depth of cut = 1.2 mm
Feed = 315 mm/rev
5. Conclusions

The influence of machining parameters on the multi responses is studied and the following conclusions are drawn from the results.

1) The order of influenced parameters found from Fuzzy-Taguchi analysis is as follows:
   - Speed (most influential);
   - Coolant (moderately influential);
   - Depth of cut (least influential);
   - Feed (very least influential).

2) Taguchi analysis shows that speed has more influence on vibrations, forces and temperature and that coolant has more influence on surface roughness.

3) Confirmation test has been conducted and results are satisfactory.

   However, this work can be extended further by considering the followings:
   - Accuracy of predictions will be enhanced by generating more experimental data for training;
   - Tools with coated materials like Titanium, diamond, etc., are to be used in order to get the best results;
   - Use of CNC machines is for automatic adjustments of parameter values.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Speed (rpm)</th>
<th>Feed (mm/min)</th>
<th>Depth of cut (mm)</th>
<th>Tool</th>
<th>Coolant</th>
<th>CNC Machine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soluble oil</td>
<td>1400</td>
<td>315</td>
<td>1.2</td>
<td>19.28</td>
<td>10.95</td>
<td>38.6</td>
</tr>
</tbody>
</table>
References


AN EXPERIMENTAL STUDY ON INFLUENCE OF COOLANTS IN DOWN MILLING OF AMMC USING TI-N COATED HSS CUTTER

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Abstract: In recent years, many researchers and authors have been investigating various aspects of Aluminium Metal Matrix composites (AMMC) because of their combined mechanical and thermal properties. It becomes a significant task to study the behaviour of AMMC during machining. By observing previous approaches on AMMC, machining of composites is very difficult under normal conditions. During milling process of AMMC using Ti-N coated HSS cutter, some problems arise because of the reinforced particles fabricated in it. High temperatures and poor surface quality were observed at shear zone during machining.

In this context, Aluminium metal matrix composite material is selected as Al- 6061 + 2% Al2O3 and Titanium Nitride (Ti-N) coated HSS helical milling cutter having a size more than composite work piece is selected. The input parameters were taken as speed, feed rate, depth of cut in a range of low, medium and high and coolants are Dry, soluble oil and veg. oil to perform the experiment. Because of various applications and reliable properties of AMMC in advance manufacturing systems, nanotechnology, mechatronics, cryogenics etc., the output parameters were selected as temperature (T) and surface roughness (R). Afterwards, Taguchi design of experiments L18 is adopted for the experiment. The values of temperature and surface roughness are noted and the optimal input machining conditions are found by using Fuzzy-Taguchi optimization technique with reference to normalized values followed by their corresponding S/N ratios of output parameters.

The effective optimum results were found by using Fuzzy-Taguchi technique and the variation between experimental and Fuzzy predicted data has been compared and concluded.

Key Words: Aluminium Metal Matrix Composite (AMMC), Slab Milling, Talysurf Meter, Laser Thermometer, Fuzzy-Taguchi Method.

1. INTRODUCTION

During machining process, friction between work piece-cutting tool and cutting tool-chip interfaces cause high temperature on cutting tool. The effect of this generated heat decreases tool life, increases surface roughness and decreases the dimensional sensitiveness of work material [1]. The essential task of the coating is to modify the contact conditions in the cutting region between the different wear surfaces reducing wear intensity, prolonging tool life and assuring the quality of the finished surface. Benefits of the coating arise from its higher hardness and wear resistance at elevated temperature, accompanied with lower friction coefficient between contacting surfaces and good chemical and thermal stability [2]. In milling, application of coolant tends to reduce tool wear and minimize adhesion of the work material on the cutting tool during machining and also improves the surface finish [3]. Small quantity of mineral oil sprayed in mist form was effective in reducing the flank wear and severity of abrasion wear, and preventing the formation of crater and the occurrence of catastrophic failure during the milling of STAVAX® (modified AISI 420 stainless steel) using Al-TiN or Ti-N coated carbide tool [4]. With the application of cutting fluid, the
tool wear reduces and machined surface quality improves [5]. Most of the cutting fluids possess the health hazard to the operator. Disposal of the used cutting fluid is also a major challenge [6]. New cutting materials increase the tool efficiency costs of performing machining operations, and also highly increase the reliability of the cutting and the quality of the products [7]. Most of the researchers was focused on minimization of surface roughness in machining and stated that minimizing the surface roughness was a serious task [8]. The cutting conditions which influence the surface quality and machining process are coolant, tool type, speed, feed, depth of cut. Among those, coolant is an important factor largely affects the machining process [9]. The modern industries are therefore looking for a cooling system to provide dry (near dry), clean, neat and pollution free machining [10].

By observing the above approaches, the present paper focuses on the influence of different coolants in down milling of AMMC and the best combination of process parameters on the basis of minimizing temperature at the interface of tool-work piece and surface roughness of work piece using Fuzzy- Taguchi optimization Technique.

2. DESIGN OF EXPERIMENTS

In the present study, mixed level of process parameters is selected based on their priority on machining i.e., two levels of feed rate, three levels of remaining parameters speed, depth of cut and coolants. Experiments were conducted on 6061+ 2% Al2O3 of size 110x50x25 mm3. The cutting tool is selected as Ti- N coated HSS cutter with a size more than the AMMC work material for its machining. The four process parameters which influence the temperature and surface roughness are identified noted in Table 1.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Levels</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Level 1</td>
</tr>
<tr>
<td>Feed rate (mm/min.)</td>
<td>400</td>
</tr>
<tr>
<td>Speed (r.p.m)</td>
<td>560</td>
</tr>
<tr>
<td>Coolant</td>
<td>Dry</td>
</tr>
<tr>
<td>Depth of cut (mm)</td>
<td>0.3</td>
</tr>
</tbody>
</table>

2.1. Coolants used in Machining Process

The different types of coolants are classified on the basis of wide usage in manufacturing industries in India and ranked below:

1. Synthetic Oils
2. Soluble Oils
3. Straight Oils
4. Semi- synthetic Oils

In this context, the two coolants namely, Synthetic oils like vegetable oils, animal oils etc., and soluble oils are selected for machining of Al- 6061+ 2% Al2O3 composite work piece.

2.2. Taguchi Design of Experiments

Based on number of influential factors and their levels, OA18 experimental design is chosen using Taguchi Design of Experiments MINITAB software and tabulated the values in table 2.

<table>
<thead>
<tr>
<th>Exp. No.</th>
<th>Feed (mm/min.)</th>
<th>Speed (r.p.m)</th>
<th>Coolant</th>
<th>Depth of Cut (mm)</th>
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<tr>
<td>1</td>
<td>400</td>
<td>560</td>
<td>Dry</td>
<td>0.3</td>
</tr>
<tr>
<td>2</td>
<td>400</td>
<td>900</td>
<td>Dry</td>
<td>0.6</td>
</tr>
<tr>
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<td>400</td>
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<td>Dry</td>
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</tr>
<tr>
<td>4</td>
<td>400</td>
<td>560</td>
<td>Sol. Oil</td>
<td>0.3</td>
</tr>
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<td>5</td>
<td>400</td>
<td>900</td>
<td>Sol. Oil</td>
<td>0.6</td>
</tr>
<tr>
<td>6</td>
<td>400</td>
<td>1120</td>
<td>Sol. Oil</td>
<td>0.9</td>
</tr>
<tr>
<td>7</td>
<td>400</td>
<td>900</td>
<td>Veg. Oil</td>
<td>0.3</td>
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<tr>
<td>8</td>
<td>400</td>
<td>1120</td>
<td>Veg. Oil</td>
<td>0.6</td>
</tr>
<tr>
<td>9</td>
<td>400</td>
<td>560</td>
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<td>0.9</td>
</tr>
<tr>
<td>10</td>
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<td>1120</td>
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<td>0.3</td>
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<tr>
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<td>800</td>
<td>560</td>
<td>Dry</td>
<td>0.6</td>
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<td>Veg. Oil</td>
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<td>18</td>
<td>800</td>
<td>900</td>
<td>Veg. Oil</td>
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</table>
After the observation of more research investigations on milling operations, ten output parameters and their nature for optimization is noted and tabulated in table 3. These process parameters are selected on the basis of influence on machining operations in many manufacturing industries in India.

From the above table, it is observed that except metal removal rate (MRR), all the output parameters have their nature as minimization for optimization. In the present work, temperature and surface roughness are selected by considering their interrelation of improving total quality of end product and maximization of profit of a firm.

3. EXPERIMENTAL INVESTIGATION:

The experimental work is investigated in down milling type of peripheral milling on Al-6061+2% Al₂O₃ AMMC with Coated Ti-N milling cutter operated on HMT horizontal milling machine. Table 4 shows the description of experimental configuration.

3.1. Measurement of Surface Roughness of the AMMC

The values of surface roughness of the machined surface of AMMC work material were measured at three different locations of surface and the average value of the trails is taken average value of surface roughness instead of final value to analyze the quality of surface finish. The Surface Roughness (Rₜ) is measured with the help of Talyuruf metering device shown in Fig. 1.

In order to get the accurate values of surface roughness, a flexible support wooden stand is used to support the Talyurf meter while taking the measurements at different locations. The flexible support stand is shown in Fig. 2.

Table 3: Output Parameters and their Nature for Optimization in Milling

<table>
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<th>S. No.</th>
<th>Output Parameter</th>
<th>Nature for Optimization</th>
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<tr>
<td>1</td>
<td>Metal Removal Rate (MRR)</td>
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</tr>
<tr>
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<td>Temperature</td>
<td>Minimum</td>
</tr>
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<td>3</td>
<td>Cutting Forces</td>
<td>Minimum</td>
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<td></td>
<td>i. Thrust force</td>
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</tr>
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<td>ii. Feed Force</td>
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</tr>
<tr>
<td></td>
<td>iii. Cross Feed Force</td>
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<td>4</td>
<td>Surface roughness</td>
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</tr>
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<td>Vibrations and frequency</td>
<td>Minimum</td>
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<td>6</td>
<td>Torque</td>
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<td></td>
<td>pattern</td>
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<td>8</td>
<td>Power consumption</td>
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<td>9</td>
<td>Quantity of coolant</td>
<td>Minimum</td>
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<td>10</td>
<td>Machining time</td>
<td>Minimum</td>
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</table>

Table 4: Description of Experimental Configuration

<table>
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<th>S. NO.</th>
<th>TOOL</th>
<th>DESCRIPTION</th>
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<tr>
<td>1</td>
<td>Machine Tool</td>
<td>HMT Horizontal milling machine</td>
</tr>
<tr>
<td>2</td>
<td>Milling Operation</td>
<td>Slab or Peripheral milling operation (Down Milling type)</td>
</tr>
<tr>
<td>3</td>
<td>Cutting Tool</td>
<td>Titanium Nitride coated HSS helical milling cutter of size 80mm x 70mm</td>
</tr>
<tr>
<td>4</td>
<td>Work Material</td>
<td>Al-6061 with 2% of Aluminum Oxide particles. Size of work material: 110x50x25 mm³</td>
</tr>
<tr>
<td>5</td>
<td>Instruments used for measure Output Parameters</td>
<td>Talyurf meter and Laser Thermometer</td>
</tr>
</tbody>
</table>

Fig 1. Talyurf Meter (surface roughness measuring device)
Table 5: Experimental Data after Investigation

<table>
<thead>
<tr>
<th>Exp. No</th>
<th>Feed (mm/min.)</th>
<th>Speed (r.p.m)</th>
<th>Coolant</th>
<th>Depth Of Cut (mm)</th>
<th>Temperature (°C)</th>
<th>Avg. Rₜ (microns)</th>
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<td>800</td>
<td>560</td>
<td>Veg. Oil</td>
<td>0.6</td>
<td>39.8</td>
<td>0.246667</td>
</tr>
<tr>
<td>18</td>
<td>800</td>
<td>900</td>
<td>Veg. Oil</td>
<td>0.9</td>
<td>43.2</td>
<td>0.12</td>
</tr>
</tbody>
</table>

3.2. Measurement of Temperature at the Interface of Tool and Work Material (AMMC)

According to theoretical approaches made by many authors, the temperature is very high at the shear zone of cutting tool and work material. The temperature increases with the increase of hardness of work material. As we discussed, AMMC have very high hardness compared to conventional alloys and super alloys. So, it is impossible to change the material properties for better machining because it depends on customer needs and end product quality. This problem can be achieved by using coated cutters with proper coolants. This scientific approach is
4. RESULTS AND CONCLUSIONS

4.1. Results

After the investigation of experiment, the values of output parameters i.e., temperature at shear zone and average surface roughness of AMMC are noted and tabulated in Table 5.

4.1.1. Taguchi Method

The output parameters are measured from the experiments and to get an effective optimum combination of input parameters, Process Performance Index (PPI) has to evaluate. PPI is evaluated by normalizing the process output parameters using Fuzzy module in MATLAB. Finally, larger PPI is selected to get effective optimum combination of input parameters in order to minimize the flank wear and surface roughness. Table 6 shows the normalizing values of temperature and surface roughness of AMMC.
4.1.2. Estimation of Optimal Levels of Process Parameters for Responses

The optimal levels of input parameters are evaluated from the response of means values in the basis of selection larger Process Performance Index (PPI) in Taguchi optimization method and values are tabulated in Table 7 and main effects plots for means is shown in Fig. 4

4.2. Conclusions

Temperature and surface finish are significant process parameters to determine the nature of machinability in any machining operation. High machinability has smooth flow of raw materials and finished products. It greatly reduces work in process inventory which directly improves productivity of a firm.

From the present study, temperature and surface roughness are evaluated to be better at high feed rates (800 mm/ min.), moderate cutting speeds (900 r.p.m.), high depth of cut (0.7) and soluble oil used as coolant from the above tables and graphs, The most affecting input variables in this approach are ranked as follows:

- Speed
- Depth of cut (mm)
- Coolant
- Feed rate (mm/min.)

The above experimental investigation give the best combination of input process parameters on the basis of minimization of temperature and surface roughness and it approximately matches with theoretical approach.

It is also concluded that Fuzzy- Taguchi method is effectively utilized to reduce the number of experiments, finding the optimal combination of the controllable parameters and to predict the experimental data.

REFERENCES


4. P. C. Siow; Sebastian Dayou; and W. Y. H. Liew: investigation of the tool wear and surface finish in low-speed milling of stainless steel under


