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# Regression Modelling of Pouring Temperature and Mechanical Properties of Aluminum Alloy Cast Using Matlab

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## ABSTRACT

*The study, regression modeling of pouring temperature and mechanical properties of aluminum alloy cast using MATLAB was successfully achieved. Researchers considered a total of thirty-two (32) Aluminum casts products produced at four (4) different pouring temperatures 660°C, 690°C, 710°C and 740°C using sand mold. Temperature measurement was done with the aid of a thermocouple. The cast products achieved were tested to determine the mechanical properties such as hardness value and tensile strength. Test results were analyzed and modeled using MATLAB. Furthermore, the standard error was observed to be 250.57 while P-value was 0.479 and degrees of freedom 1 with root mean squared error of 24.3 were observed in tensile strength and pouring temperature model. Graphs plotted suggested that maximum and best value of tensile strength and hardness value would occur at pouring temperature of 690℃. Also, the standard error was observed to be 520.33 while P-value was 0.715 and degrees of freedom 1 with root mean squared error of 32.1 were observed in hardness value and pouring temperature model. The P-value and degrees of freedom of the generated linear regression model are consistent with the P-value and degrees of freedom of ANOVA model, that proves correctness of the model. The non linear regression modeling between the selected variables returned no answer. More so, correlation coefficient of 0.7297 and p-value coefficient of 0.4793 for tensile strength and correlation coefficient of 0.4336 and p-value coefficient of 0.7145 for hardness value respectively, from data analysis indicated that there is positive and significant relationship between tensile strength, hardness value and pouring temperature of Aluminum Alloy cast.*

*Keywords:* Mechanical properties, Pouring temperature, Aluminum alloy cast, Matlab, Anova.

## INTRODUCTION

It has been the interest of the researchers to determine and predict the relationship between the pouring temperature and mechanicals properties of Aluminum Alloy cast over decades. According to Jonathan (2003) as cited in Iweriolor et al., (2024) Aluminum Alloy casts play major role in the automotive industrial sector, in the production of components such as pistons, cylinder blocks, cylinder heads, cylinder liners, bearings, connecting rods, turbo chargers, jet engine parts, impellers, metal composites, actuators, brake calipers and rotors. Increase in the performance, efficiency and reliability of these cast parts for service has been found to be proportional to the improvement in their mechanical properties. In addition, the mechanical properties are affected by the pouring temperature during casting. Therefore, this necessitated the need to understand and predict the relationship between them.

Regression modeling here is a non linear and linear approach for modeling the relationship between a dependent variable pouring temperature and one independent variable any mechanical property of Aluminum Alloy cast; where other influencing factors are kept constant.

Therefore, the mechanical properties of a cast are of uttermost importance to the end usage and usefulness of that cast. Such properties include ductility and workability, strength, density, water retention capacity, thermal expansion and conductivity, modulus of elasticity, etc. For example, an aluminum alloy cast having a high tensile strength at elevated temperatures, excellent resistance to corrosion in the atmosphere and water, high thermal conductivity and relatively light weight will be the ultimate asset in the industry, such as the electrical, marine, aviation, construction, aeronautic, aerospace and automotive industries.

The composition of the Aluminum Alloy sample adopted by the paper includes Al (83%), Si (11%), and Cu (3%). According to Oji et al., (2011) as cited in Iweriolor et al., (2024) stated that Aluminum Alloy casting process are influenced by melting temperature of the charge, temperature of the mold, pouring speed, pouring temperature, composition, micro structure, size of casting, runner size, and solidification time. But the modeling in this paper considered pouring temperature and mechanical properties.

The inadequacies in mechanical properties of Aluminum Alloy cast might be attributed to their pouring temperature during casting. Therefore, it is of paramount to determine the mathematical relationship between the pouring temperature and mechanical properties of aluminum alloy cast for prediction. Hence, the paper aimed at studying regression modeling of pouring temperature and mechanical properties of aluminum alloy cast using MATLAB.

## METHODOLOGY

This study considered a total of thirty-two (32) Aluminum casts produced at four (4) different pouring temperatures 660°C, 690°C, 710°C and 740°C using sand mold. Temperature measurement was done with the aid of a thermocouple. The cast products achieved were tested to determine the mechanical properties such as density, hardness, water retention capacity and tensile strength. The test results were analyzed and modeled using matlab.

## RESULTS

Mechanical properties of Aluminum Alloy Cast specimen results data are presented below.

Table 1.0: Masses of the Casts and Their Pouring Temperatures (Source: Iweriolor et al., 2024)

| MASS | POURING TEMPERATURE (°C) | | | |
|---|---|---|---|---|
| | 660°C | 690°C | 710°C | 740°C |
| | 400 | 403 | 378 | 383 |
| | 402 | 414 | 390 | 399 |
| | 409 | 409 | 366 | 358 |
| | 411 | 393 | 373 | 364 |
| | 420 | 417 | 350 | 348 |
| | 417 | 390 | 377 | 374 |
| | 398 | 401 | 387 | 349 |
| | 399 | 384 | 370 | 345 |

Table 2.0: Values for Tensile Strength (Source: Iweriolor et al., 2024)

| TENSILE STRENGTH | TEMPERATURE (°C) | | | |
|---|---|---|---|---|
| | 660°C | 690°C | 710°C | 740°C |
| | 141.5 | 151.2 | 141.0 | 131.7 |
| | 149.0 | 162.2 | 153.3 | 133.5 |
| | 134.1 | 154.1 | 155.1 | 150.1 |
| | 134.1 | 149.3 | 150.2 | 145.3 |
| | 139.4 | 154.1 | 150.3 | 140.7 |
| | 130.3 | 153.2 | 144.2 | 132.2 |
| | 129.8 | 159.6 | 148.1 | 131.9 |

>> **% LINEAR MATLAB PROGRAMME FOR POURING TEMP. AND MECH. PROPERTIES**

>> % X = POURING TEMPERATURE

```
>> % Y = MECHANICAL PROPERTY; TENSILE STRENGTH

>> X = [660 690 710];

>> Y = [141.5 162.2 155.1];


>> mdl = fitlm(Y,X)

mdl =

Linear regression model:

  y ~ 1 + x1


Estimated Coefficients:

              Estimate     SE      tStat    pValue
              _____   _____   _____   _____

  (Intercept)   419.67    250.57   1.6748   0.34267

  x1            1.7459    1.6359   1.0672   0.47931

Number of observations: 3, Error degrees of freedom: 1

Root Mean Squared Error: 24.3

R-squared: 0.532,  Adjusted R-Squared 0.065

F-statistic vs. constant model: 1.14, p-value = 0.479

  >>End
```

**>> TBL = ANOVA (MDL)**

```
tbl =
          SumSq   DF   MeanSq     F       pValue
          _____   __   _____   _____   _____

  x1      238.1    1   238.1    0.23148   0.71452

  Error   1028.6   1   1028.6
```


```
>>End
```

The computed linear regression model between pouring temperature and mechanical property of Aluminum Alloy cast is shown below;

$$Y = 1.7459X - 419.67$$

**Where Y = Mechanical Property, Tensile Strength in MPa or N/mm2 and X = Pouring Temperature in ℃.**

**>> %NON LINEAR MATLAB PROGRAMME FOR POURING TEMP. AND MECH. PROPERTIES**

```
>> % X = POURING TEMPERATURE

>> % Y = MECHANICAL PROPERTY; TENSILE STRENGTH

>> X = [660 690 710];

>> Y = [141.5 162.2 155.1];

>> modelfun = @(b,x)b(1) + b(2)*x(:,1).^b(3);

>> beta0 = [660 690 710];

>> mdl = fitnlm(X,Y,modelfun,beta0)

Error using nlinfit>checkFunVals (line 636)
```

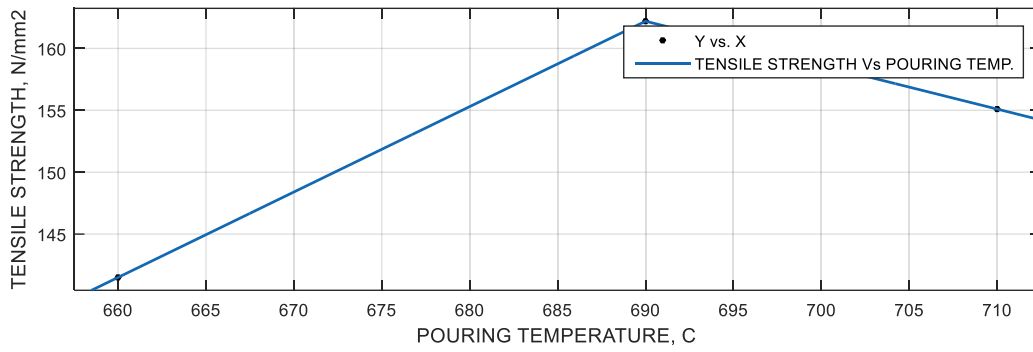The function you provided as the MODELFUN input has returned Inf or NaN values.

>>End



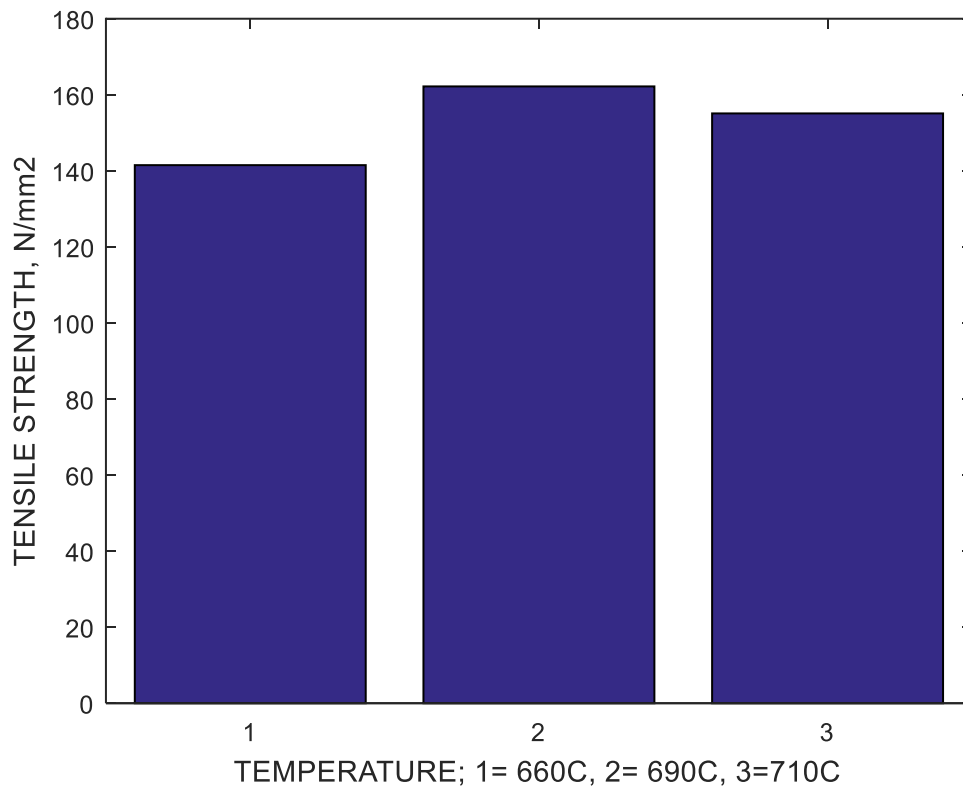**Fig 1.0: Graph of Tensile Strength against Pouring Temperature**



**Fig 2.0:  Bar Graph of Tensile Strength against Pouring Temperature**

**LINEAR INTERPOLANT**

f(x) = piecewise polynomial computed from p

where x is normalized by mean 686.7 and std 25.17

Coefficients: p = coefficient structure

Goodness of fit:

  SSE: 0

  R-square: 1

  Adjusted R-square: NaN

  RMSE: Na

*MATLAB CODES/SCRIPTS OF THE GRAPH ABOVE*

```
function createfigure1(XData1, YData1, XData2, YData2)

%CREATEFIGURE1(XDATA1, YDATA1, XDATA2, YDATA2)

%  XDATA1:  line xdata

%  YDATA1:  line ydata

%  XDATA2:  line xdata

%  YDATA2:  line ydata

% MATLAB on 16-Mar-2024 12:31:13

% Create figure

figure1 = figure('Tag','Print CFTOOL to Figure',...

    'Color',[0.941176470588235 0.941176470588235 0.941176470588235]);

% Create axes

axes1 = axes('Parent',figure1,'Tag','sftool surface axes');

%% Uncomment the following line to preserve the X-limits of the axes

% xlim(axes1,[657.5 712.5]);

%% Uncomment the following line to preserve the Y-limits of the axes

% ylim(axes1,[140.46 163.24]);

%% Uncomment the following line to preserve the Z-limits of the axes

% zlim(axes1,[-1 1]);

box(axes1,'on');

grid(axes1,'on');

hold(axes1,'on');

% Create line

line(XData1,YData1,'Parent',axes1,'DisplayName','Y vs. X',...

    'MarkerFaceColor',[0 0 0],...

    'MarkerEdgeColor',[0 0 0],...

    'MarkerSize',3,...

    'Marker','o',...

    'LineStyle','none');

% Create line

line(XData2,YData2,'Parent',axes1,'DisplayName','TENSILE STRENGTH Vs POURING TEMP.',...

    'LineWidth',1.5,...

    'Color',[0.0705882352941176 0.407843137254902 0.701960784313725]);

% Create xlabel

xlabel({'POURING TEMPERATURE, C'});

% Create ylabel

ylabel({'TENSILE STRENGHT, N/mm2'});
```

% Create zlabel

zlabel('Z');


% Create legend

legend1 = legend(axes1,'show');

set(legend1,'Interpreter','none','EdgeColor',[0.15 0.15 0.15]);

 >>End

Table 3.0:  Hardness Value (Source: Iweriolor et al., 2024)

| HARDNESS | TEMPERATURE (°C) | | | |
|---|---|---|---|---|
| | 660°C | 690°C | 710°C | 740°C |
| | 41.6 | 44.5 | 41.5 | 38.7 |
| | 43.8 | 47.7 | 45.1 | 39.3 |
| | 39.4 | 45.3 | 45.6 | 44.1 |
| | 39.4 | 43.9 | 44.2 | 42.7 |
| | 41.0 | 45.3 | 44.2 | 41.4 |
| | 38.3 | 45.1 | 42.4 | 38.9 |
| | 38.2 | 46.9 | 43.6 | 38.8 |
| | 38.8 | 46.6 | 43.4 | 38.1 |

**>> %MATLAB PROGRAMME FOR POURING TEMP. AND MECH. PROPERTIES**

**>> % X = POURING TEMPERATURE**

**>> % Y = MECHANICAL PROPERTY= HARDNESS VALUE**

>> X = [660 690 710];

>> Z = [43.8 47.7 45.1];

>> mdl = fitlm(Z,X)

mdl =

Linear regression model:

   y ~ 1 + x1

Estimated Coefficients:

```
              Estimate    SE      tStat     pValue
              _____  _____  _____  _____

  (Intercept)   436.48   520.33   0.83887   0.55564

  x1            5.4945    11.42   0.48113   0.71452
```

Number of observations: 3, Error degrees of freedom: 1

Root Mean Squared Error: 32.1

R-squared: 0.188,  Adjusted R-Squared -0.624

F-statistic vs. constant model: 0.231, p-value = 0.715

>>End

The computed linear regression model between pouring temperature and mechanical property of Aluminum Alloy cast is shown below;

$$Y = 5.4945X - 436.48$$

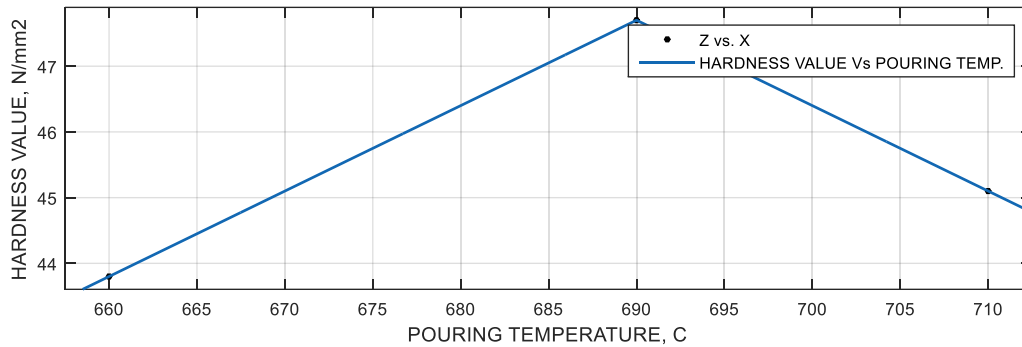**Where Y = Mechanical Property, Hardness Value in MPa or N/mm2 and X = Pouring Temperature in °C.**



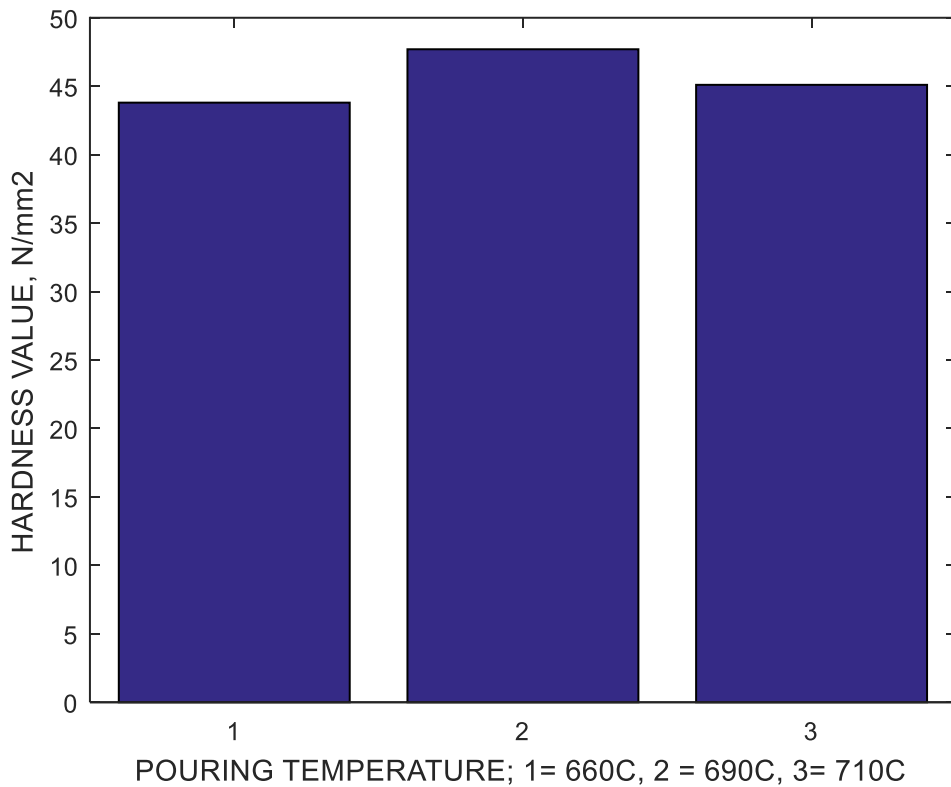**Fig 3.0: Graph of Hardness value against Pouring Temperature**



**Fig 4.0: Bar Graph of Hardness value against Pouring Temperature**

**MATLAB CODES/SCRIPTS OF THE GRAPH ABOVE**

function createfigure1(XData1, YData1, XData2, YData2)

%CREATEFIGURE1(XDATA1, YDATA1, XDATA2, YDATA2)

%  XDATA1:  line xdata

%  YDATA1:  line ydata

%  XDATA2:  line xdata

%  YDATA2:  line ydata

```
% MATLAB on 16-Mar-2024 12:58:51

% Create figure

figure1 = figure('Tag','Print CFTOOL to Figure',...

    'Color',[0.941176470588235 0.941176470588235 0.941176470588235]);

% Create axes

axes1 = axes('Parent',figure1,'Tag','sftool surface axes');

%% Uncomment the following line to preserve the X-limits of the axes

% xlim(axes1,[657.5 712.5]);

%% Uncomment the following line to preserve the Y-limits of the axes

% ylim(axes1,[43.605 47.895]);

%% Uncomment the following line to preserve the Z-limits of the axes

% zlim(axes1,[-1 1]);

box(axes1,'on');

grid(axes1,'on');

hold(axes1,'on');

% Create line

line(XData1,YData1,'Parent',axes1,'DisplayName','Z vs. X',...

    'MarkerFaceColor',[0 0 0],...

    'MarkerEdgeColor',[0 0 0],...

    'MarkerSize',3,...

    'Marker','o',...

    'LineStyle','none');

% Create line

line(XData2,YData2,'Parent',axes1,...

    'DisplayName','HARDNESS VALUE Vs POURING TEMP.',...

    'LineWidth',1.5,...

    'Color',[0.0705882352941176 0.407843137254902 0.701960784313725]);

% Create xlabel

xlabel({'POURING TEMPERATURE, C'});

% Create ylabel

ylabel({'HARDNESS VALUE, N/mm2'});

% Create zlabel

zlabel('Z');

% Create legend

legend1 = legend(axes1,'show');

set(legend1,'Interpreter','none','EdgeColor',[0.15 0.15 0.15]);
```

**CORRELATION COEFFICIENT FOR TENSILE STRENGTH AND POURING TEMPERATURE**

```
>> [R,P] = corrcoef(X,Y)

R =
```

1.0000　0.7297

0.7297　1.0000

P =

1.0000　0.4793

0.4793　1.0000

**CORRELATION COEFFICIENT FOR HARDNESS VALUE AND POURING TEMPERATURE**

>> [R,P] = corrcoef(X,Z)

R =

1.0000　0.4336

0.4336　1.0000

P =

1.0000　0.7145

0.7145　1.0000

## DISCUSSION

The results of the study, regression modeling of pouring temperature and mechanical properties of aluminum alloy cast using MATLAB were discussed here. Researchers achieved the study using variable pouring temperatures of 660℃, 690℃, 710℃ and 740℃ which yielded variable tensile strength and hardness value as shown in table 2.0 and table 3.0 respectively.

The MATLAB analysis computed the linear regression model between tensile strength and pouring temperature

$$Tensile\ Strength = 1.7459 \times Pouring\ Temperature - 419.67$$

**Where Tensile Strength is in MPa or N/mm2 and  Pouring Temperature is in ℃.**

The standard error was observed to be 250.57. The P-value　0.479 and degrees of freedom 1 with root mean squared error of 24.3. The graph of **Fig. 1.0**, suggested that maximum and best value of tensile strength would occur at pouring temperature of 690℃.

Computed also was linear regression model between hardness value and pouring temperature as shown below;

$$Tensile\ Strength = 5.4945 \times Pouring\ Temperature - 436.48$$

**Where Tensile Strength is in MPa or N/mm2 and Pouring Temperature is in ℃.**

The standard error was observed to be 520.33. The P-value　0.715 and degrees of freedom 1 with root mean squared error of 32.1. The P-value and degrees of freedom of the generated linear regression model are consistent with the P-value and degrees of freedom of ANOVA model, that proves correctness of the model.

The graph of **Fig. 3.0**, suggested that maximum and best value of hardness value would occur at pouring temperature of 690℃. The non linear regression modeling between the selected variables returned no answer.

The correlation coefficient of 0.7297 and p-value coefficient of 0.4793 from data analysis indicated that there is positive and significant relationship between

Tensile strength and pouring temperature of Aluminum Alloy cast.  In addition, the correlation coefficient of 0.4336 and p-value coefficient of 0.7145 from data analysis indicated that there is positive and significant relationship between

Hardness value and pouring temperature of Aluminum Alloy cast.

## CONCLUSION

The regression modeling of pouring temperature and mechanical properties of aluminum alloy cast using MATLAB was obviously achieved. Undoubtedly, results revealed that at any given value of pouring temperature of Aluminum Alloy cast, tensile strength and hardness value of cast product could be easily computed.

## RECOMMENDATIONS

The following recommendations are suggested based on the study:

1) To improve mechanical properties of Aluminum Alloy cast, optimal pouring temperature should be 690℃.

2)  The model should be used to establish pouring temperature when initial values tensile strength and hardness are chosen.

**3)** This research could also be done in future using variable mixture of Aluminum Alloy sample, thicker masses and other advanced software like simulink for generalization.

## LIMITATION OF THE STUDY

In the course of carrying out this research, regression modeling of pouring temperature and mechanical properties of aluminum alloy cast using MATLAB, the researchers encountered many hindrances which might cause deviations from actual results. Some of the hindrances includes: mold and pattern building difficulties, cost of data analysis, lack of electricity, material sourcing, etc.

### DISCLOSURE OF CONFLICT OF INTEREST

We hereby declare that this research article is original and the corresponding author confirms that co-authors participated actively in the development of the paper and have read and approved the manuscript with no ethical issues and with declaration of no conflict of interest.

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