# EFFECT OF SOME FACTORS IN THE FRICTION STIR WELDING ON TENSILE STRENGTH OF AL-Zn-Mg ALLOY.

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## ABSTRACT

Friction Stir Welding ( FSW ) is a solid –state process that leads to several advantages over the fusion welding methods. This is used in the welding of several non-expendable and is also responsible for generating sufficient heat for welding and the resulting friction. Rotational speed, as well as the welding speed- both play a major role to obtain the weld quality. This research examines the effect of the rotation speed and welding speed on the tensile properties of the Al-Zn-Mg by the Minitab 16 program used. It was concluded that the best tensile strength of (158Mpa) can be obtained when the variables were ($X_1$ = 900 rpm) ($X_2$ =52mm\min).Also results show that the variables, namely the rotation Speed ($X_1$) &welding speed ($X_2$) have a significant effect on tensile strength. However, the interactions of these factors have less significant effect on tensile strength. Moreover, the tensile strength increases with the increasing welding speed and decreasing rotation speed.

**Keyword:** friction stir welding, Al-Zn-Mg alloy ,tensile strength, hardness, rotation speed, welding speed.

# تأثير بعض متغيرات لحام الخلط الاحتكاكي على مقاومة الشد لسبيكة ألمنيوم زنك مغنيسيوم

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**الخلاصة:**

يعتبر لحام لخلط الاحتكاكي من أنواع لحام الحالة الصلبة والذي يتميز بخواص ميكانيكية متقدمة عن اللحام الأنصهاري . يستخدم في هذا اللحام عدة غير مستهلكة والتي تكون مسئولة عن توليد الحرارة الكافية للحام و الناتجة عن الاحتكاك. السرعة الدورانية و السرعة الخطية تلعبان دور رئيسي في الحصول على نوعية جيدة للحام . يتناول هذا البحث دراسة تأثير سرعة الدوران والسرعة الخطية على مقاومة الشد لسبيكة Al-Zn-Mg باستخدام برنامج MINITAB16. تم استنتاج أن أفضل مقاومة شد (158Mpa) والتي يمكن الحصول عليها عندما تكون سرعة الدوران ($X_1$=900rpm) وسرعة الخطية ($X_2$= 52mm\min). كذلك تبين من النتائج أن المتغيرات سرع الدوران والسرع الخطية لهما تأثير معنوي على مقاومة الشد,على كل حال إن التأثير المشترك للمتغيرات يكون اقل أهمية على مقاومة الشد. بالإضافة إلى أن مقاومة الشد تزداد مع زيادة السرع الخطية وانخفاض سرع الدوران.

## 1-INTRODUCTION:

Friction stir welding (FSW) is one of the new methods of welding developed nowadays. Friction stir welding is a solid state welding process. The FSW technique is attractive for joining high strength aluminum alloys since there is far lower heat input during the process compared with conventional welding processes such as TIG, MIG **[Ericsson,2003][ Thomas,2002].** This process is being used in a wide variety of applications in the automotive, aerospace, ship building, and railroad industries **[Rendigs,1997].** In FSW, the interaction of a non-consumable and rotating tool with the work pieces being welded, creates a welded joint through frictional heating and plastic deformation at temperatures below the melting temperature of the alloys being joined. Based on the friction heating at the contacting surfaces of two sheets to be joined, a special tool with a properly designed rotating probe travels down the length of contacting metal plates, producing a highly plastically deformed zone through the associated stirring action **[Arbegast,2007].**The Friction Stir Welding method of joining is based on the fact that the metal is subjected to heavy plastic deformation at high temperatures, but lower than the melting point, thus the basic concept of the FSW is remarkably simple, where a rotating tool with the pin and shoulder is inserted in the material to be welded, and traversed along the line of interest as shown in Fig.1**[Qasim,2010].** The tool serves three primary functions (1) the heating of the work piece, (2) the movement of material to produce the joint, and (3) the containment of the hot metal beneath the tool shoulder , the heating is generated by the friction between the rotation tool (shoulder and probe) and the work piece and by the plastic deformation of the work piece. The localized heating softens the material around the tool probe and then it combines with the tool shoulder and probe rotation and translation further leading to the movement of the material from the front to the back of the probe to fill the hole in the tool wake as the tool moves forward. **[Kumar,2008]** investigated the influence of the axial load and the position of the interface with respect to the fact that the tool axis on the tensile strength of the friction stir welded joint has been investigated. The axial load is continuously varied by linearly increasing the interference between the tool shoulder and the surface of the base material; the base material used is Al-Zn-Mg alloy, 7020-T6, and it is found that there is an optimal axial load above which the weld is defect-free. **[Gaafer,2010]**studied the mechanical and micro structural characteristics of friction stir-welded AA7020-0 Aluminum plate. It has been found that increasing the tool rotational speed and/or reducing the welding speed increase the primary Al phase grain size as well as the size of the precipitates at the center of the stirred zone. The tensile characteristics of the friction stir welded tensile samples depend significantly on both the tool rotational and welding speeds. In this research, the experiments are designed and the experimental data are analyzed using the software MINITAB 16.A correlation is established between input parameters and mechanical properties. The ANOVA is employed to investigate the influence of the input parameters, namely the rotational speed($X_1$) and welding speed ($X_2$) on the tensile strength of the weld. **[Morteza,2013]** dealt with Evaluation of Dissimilar Welds of 5083-H12 and 6061-T6 Produced by Friction Stir Welding. States that as the conventional fusion welding is not desirable for welding aluminum alloys, there are many works conducted on welding the aluminum alloys by FSW. These works are in regard to the effects of FSW parameters on weld quality, sheet formability after FSW, and optimization of the FSW process. [**Divya,2014**]study the optimization of FWS parameters for 6061 and 7039 aluminum alloys by RSM.

## 2-EXPERIMENTAL PROCEDURE:

The chemical composition of AL-Zn-Mg alloys is given in **Table 1**, and here, a machine was used in the welding process as shown in **Fig.2A**. The welded plates were (200 mm) in length, (100 mm) in width, and (5 mm) in thickness as shown in **Fig.2B**, then two equipped aluminum pieces were clamped into the fixture. Plate edges to be weld were also prepared so that they are fully parallel to each other. Then the rotating tool was made to be inserted into the butt joint. Then after some time, when there was adequate heating due to the friction between the tool and plates, the tool was given an automatic feed, along the joint direction. Thus the welding was achieved. After welding, the pieces were cut into the samples of mandatory dimensions for performing the tensile tests (Y). The welding tool used in this study was made of tool steel with 18mm shoulder diameter, 6mm pin diameter and 6 mm pin length . **Fig.3** indicates that the tool design was used for the FSW process. The tensile strength of the FSW Al-Zn-Mg was measured by the (3)mm thickness plate specimens-those were extracted in perpendicular to the weld direction from the (5) mm FSW plate as shown in **Fig. 4.** In these tensile specimens, the weld surface and root surface were removed with the layers measuring (1) mm in thickness. The tensile test specimen are prepared according to th ASTM-E8M standards. The levels of the model were shown in **Table 2**.The design matrix and experimental result are shown in **Table 3**.

### 3-1 Statically analysis:

Based on the experimental results **Table 4**, the linear regression model used MINITAB 16.The regression equation is given in equation 1 and equation 2.

$$Y=12.342+1.202X_1+0.187X_2+0.030X_1^2-O.O16X_2^2+0.020X_1X_2 \qquad (1)$$

The significant P-value is 0.05, and any value greater than this is regarded as insignificant and can be neglected. The regression equation can be re-written as such,

$$Y=12.342+1.202X_1+0.187X_2+0.020X_1X_2 \qquad (2)$$

Where the variables represent ($X_1$) ($X_2$) or namely the rotational speed and welding speed respectively, (Y) represents the tensile strength. It is noted from equation (2), that the rotational speed ($X_1$) has the greatest influence on the tensile strength, While the impact of welding speed ($X_2$) has less effect compared to ($X_1$).In addition to the effect of the variables individually, it is also observed that there is a shared effect of the variables on the tensile strength. **Fig.5** shows the stress-strain curve for the less tensile strength, amounting to(122Mpa).

### 3-2 Analysis of Variance (ANOVA):

The ANOVA test was used to determine that the design parameters significantly have an influencing power towards the tensile strength .Depending on the level of significance (0.05) and using the test (F-test) of the regression model, from **Table 5** , it is noted that the probabilistic value (P-value) is less than 5%, and this means that the Regression model is significant **[Venkatprasa,2011].** This result is satisfactory. R-sq Adjusted is equal to (**92.09%**), and this means that the independent variables ($X_1$, $X_2$) explain (**92.09%**) of the variables that occur in variable (Y) and the remainder is due to other factors such as random error. Whenever the coefficient of determination is closed one of the best and this can be satisfactory results.

### 3-3Interaction plot (between $X_1$and $X_2$):

Figure 6 illustrates the interaction effects of the control parameters; it is well known that any interaction does not occur when the line on the interaction plots is parallel and strong interaction will tend to occur between parameters when the lines cross**[Pascal,2009].**An examination of the tensile strength as shown in figure 6 demonstrates a small interaction between the control parameters.

### 3-4 Normal probability plot:

The normal probability plot is a graphical technique for assessing whether or not a data set is approximately normally distributed. The data is plotted against a theoretical normal distribution in such a way that the points should form an approximate straight line. Departures from this straight line indicate departures from normality. Normal probability plots were generated by using computer software MINITAB16. In **Fig.7**, it can be seen that all data residuals are approximately normally distributed because the overall points make an approximate straight line.

### 3-5 The Main Effect Plot of Tensile Strength:

**Fig. 8** shows the effect of the rotational speed and welding speed on the tensile strength and individual form. It is noted that the tensile strength decreases gradually with the increasing rotational speed and this is attributed by the high rotational speed results in the metallurgical transformation such as solubilisation, re-precipitation, and coarsening of strengthening precipitates at the weld zone and the lowering of the dislocation density which decreases the tensile strength. It is clear that in the FSW as the rotational speed increases the heat input also increases. These results almost agree with **[Palanivel,2011].** While the tensile strength improved with the rise in the value of the welding speed as the increase welding speed reduced the amount of the heat input, this enhances the tensile strength. These results agree with **[Saad,2007].** It is observed that the best result of the tensile strength was (158Mpa) at lower rotation speed (900 rpm)and higher welding speed (52mm\min).

### 3-6 Response surface analysis:

The main objective of the response surface plot is to determine the optimum operating conditions represented by the rotational speed, also the welding speed, which lead to the maximum tensile strength required.

**Fig.9 A and 9,** show a contour and a three-dimension plot which describe the effect of factors ($X_1$, $X_2$) on response (Y). The three-diminution plot shows that the tensile strength is affected by the rotational speed and the welding speed, whereas the contour plot shows an increase in the tensile strength with the decreasing rotational speed and the rise of the welding speed . It is observed that the value of the tensile strength was (155.646 Mpa) at the rotational speed was (904.890 rpm) and the welding speed was (51.1777mm\min) whereas the value of the tensile strength decreases to (123.918) at the rotational speed was (1487.92 rpm) and the welding speed was (28.7811 mm\min).

### 3-7 Pareto chart :

**Fig. 10** shows the effect of variables ($X_1$) and ($X_2$) on the tensile strength (Y) using the Pareto Chart. It has been observed that the rotation speed has the greatest influence on the tensile strength while the welding speed has a weaker influence on the tensile strength. The best result can be obtained , according to the chart at the lower value of the rotational speed and the highest value for the welding speed. High rotational speed generates high temperature as a result of friction between the tool and the metal , when the increase of the rotation speed leads to a rise in the maximum temperature in the weld zone, as well as the fact that the welding speed has an effect on the inside heat to the weld zone. This heat decreases at low welding speed **[Venkatprasat,2011].** Therefore, the best result can be obtained when the rotation speed is decreased and the welding speed increased.

## 5-CONCLUSIONS:

1- Possibility of using of FSW method in welding aluminum zinc alloy which are difficult welded by conventional methods.

2-Regression models can be represented by the following equation

$Y=12.342+1.202X_1+0.187X_2+0.020X_1X_2$.

Where the $X_1$ and $X_2$ have a significant effect on tensile strength ,and note that $X_1$ has the greatest influence compared with that of $X_2$.

3-The decrease in the rotational speed and increase in the welding speed lead to the increase and improvement of the tensile strength.

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**Table (1):** chemical composition of Al-Zn-Mg

| Elements | Zn | Mg | Mn | Si | Cu | Fe | Al |
|---|---|---|---|---|---|---|---|
| Al-Zn-Mg alloy | 4.43 | 2.27 | 0.43 | 0.3 | 0.03 | 0.53 | Bal. |

**Table (2):** FWS parameters and their levels

| No | Parameters | Code | Unit | Levels | | |
|---|---|---|---|---|---|---|
| | | | | -1 | 0 | +1 |
| 1 | Rotation speed | $X_1$ | rpm | 900 | 1200 | 1500 |
| 2 | Welding speed | $X_2$ | mm\min. | 28 | 40 | 52 |

**Table (3):** Design matrix and experimental **result**

| No run | codes | | Input parameters | | Response |
|---|---|---|---|---|---|
| | ($X_1$) | ($X_2$) | Rotation speed (rpm) | Welding speed (mm\min) | Tensile strength (Y) (Mps) |
| 1 | +1 | +1 | 1500 | 52 | 131 |
| 2 | 0 | +1 | 1200 | 52 | 140 |
| 3 | -1 | +1 | 900 | 52 | 158 |
| 4 | +1 | 0 | 1500 | 40 | 128 |
| 5 | 0 | 0 | 1200 | 40 | 144 |
| 6 | -1 | 0 | 900 | 40 | 151 |
| 7 | +1 | -1 | 1500 | 28 | 122 |
| 8 | 0 | -1 | 1200 | 28 | 136 |
| 9 | -1 | -1 | 900 | 28 | 145 |

**Table (4):** Response Surface Regression: Y versus $X_1$,$X_2$

| Term | Coef | T-value | P-value |
|---|---|---|---|
| Constant | 12.342 | 2.572 | 0.000 |
| $X_1$ | 1.202 | -0.114 | 0.017 |
| $X_2$ | 0.187 | 1.444 | 0.011 |
| $X_1*X_1$ | 0.030 | -0.366 | 0.231 |
| $X_2*X_2$ | -0.016 | -1.025 | 0.421 |
| $X_1*X_2$ | 0.020 | -0.621 | 0.041 |

**Table (5):** Analysis of Variance for Y

| Source | DF | Seq SS | Adj SS | Adj MS | F-value | P-value |
|---|---|---|---|---|---|---|
| Regression | 5 | 1017.11 | 1017.11 | 203.422 | 19.62 | 0.017 |
| Residual Error | 3 | 31.11 | 31.11 | 10.370 | | |
| Total | 8 | 1048.22 | | | | |
| S = 1.21026 | | R-Sq = 97.03% | | | R-Sq(adj) = 92.09% | |

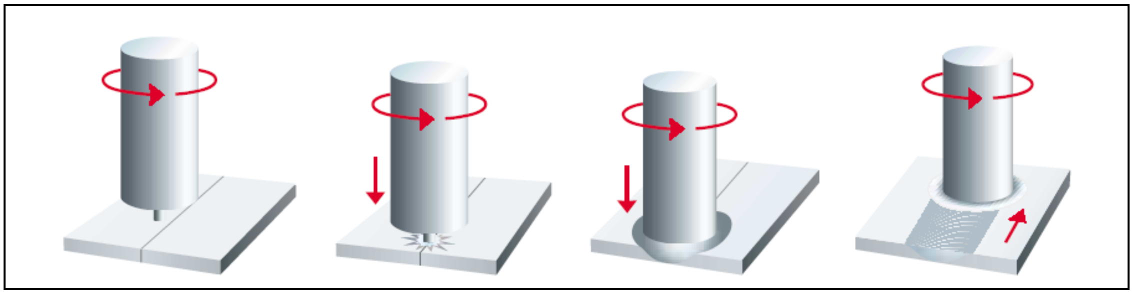

**Figure (1):** Schematic illustrations of the friction stir welding process [5].

**Figure (2A):** FSW Machine.

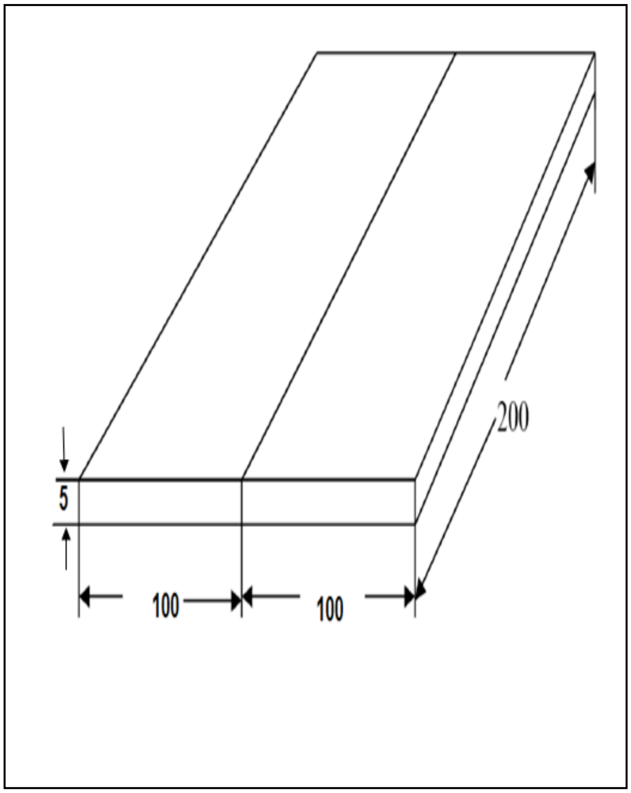


**Figure (2B):** Plate prepared for FSW.

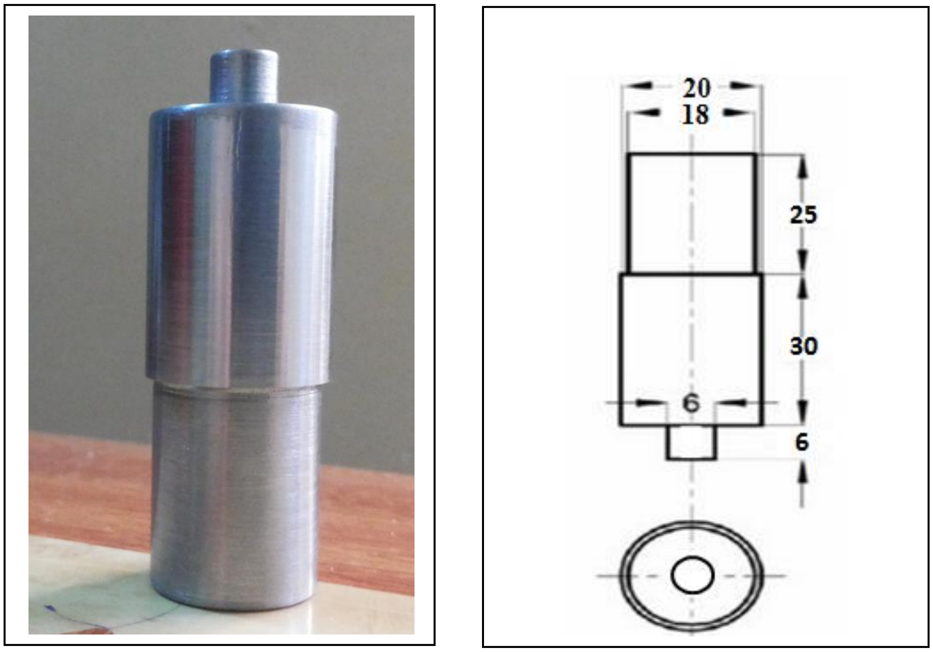


**Figure (3):** FWS tool.

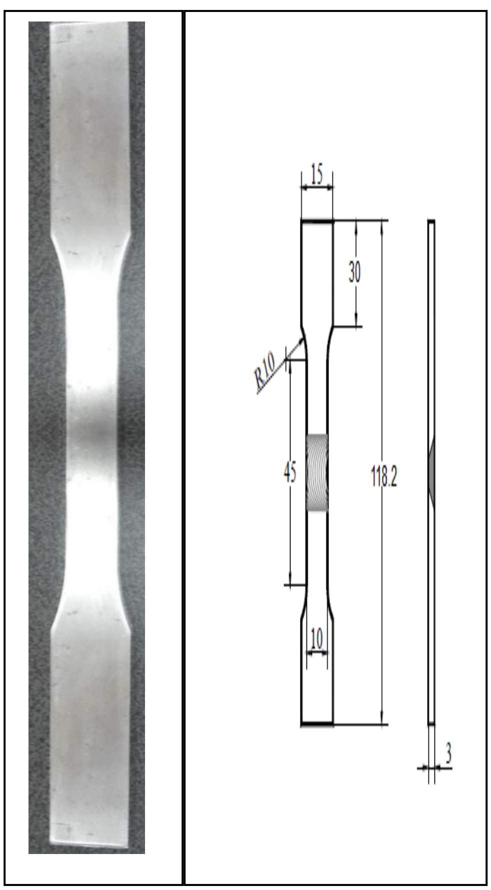


**Figure (4):** Specimen of tensile test.

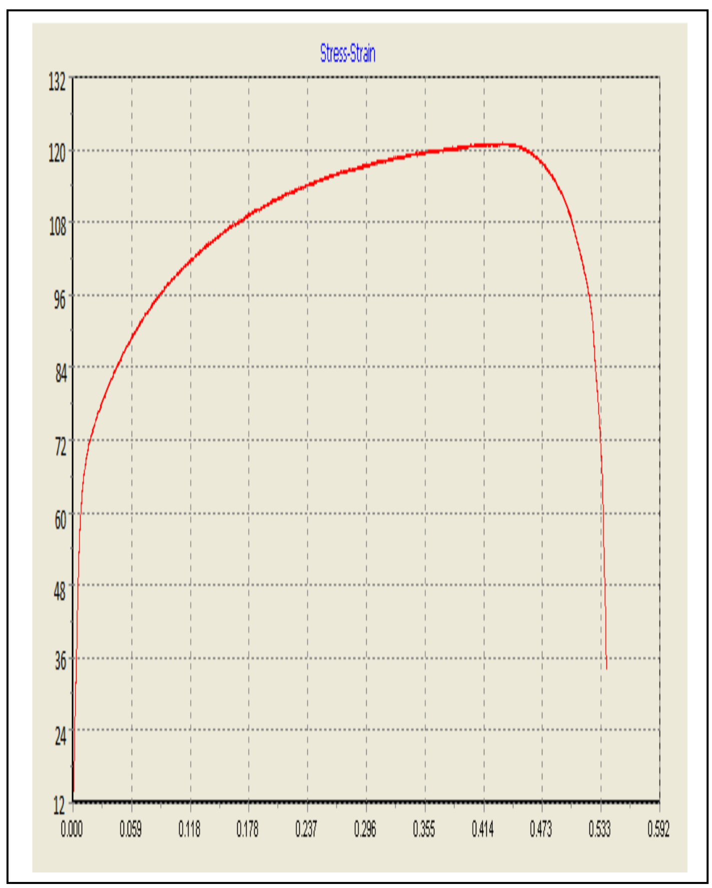


**Figure (5):** Stress strain curve (run5).

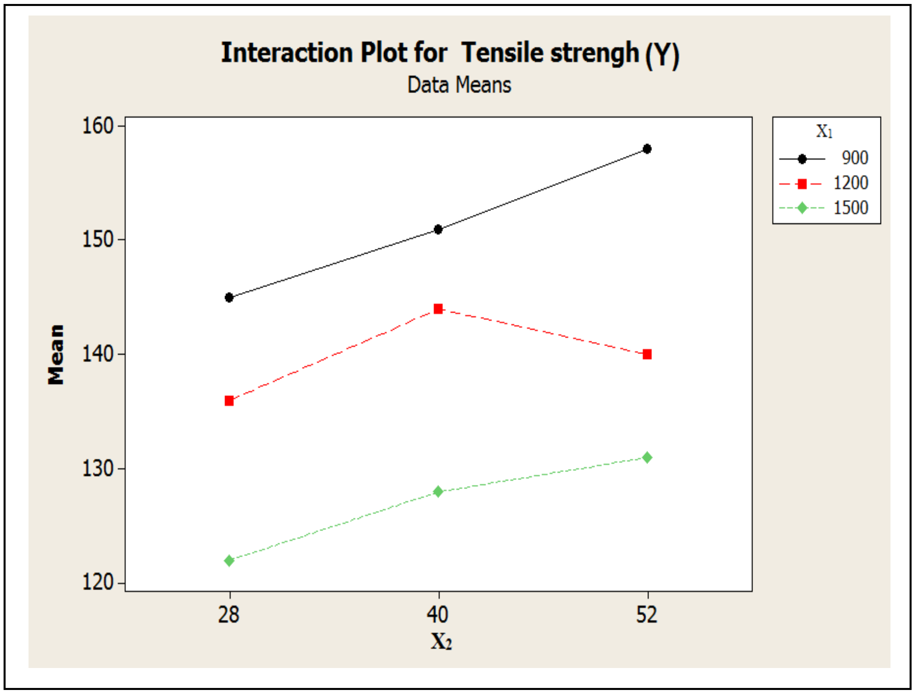


**Figure (6):** Interaction plot for tensile **strength**

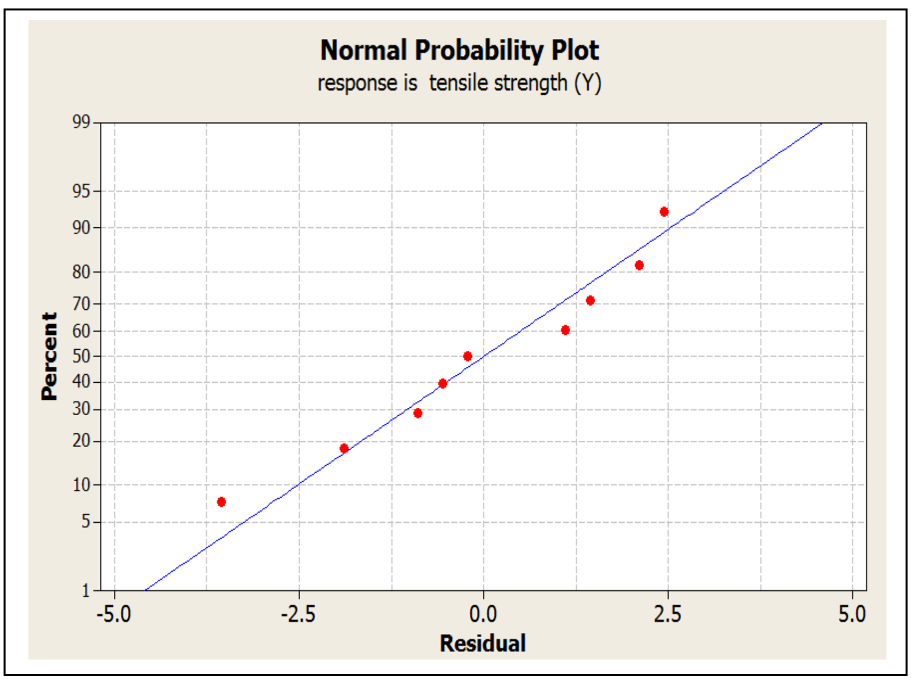


**Figure (7):** Normal probability plot of residuals of tensile strength

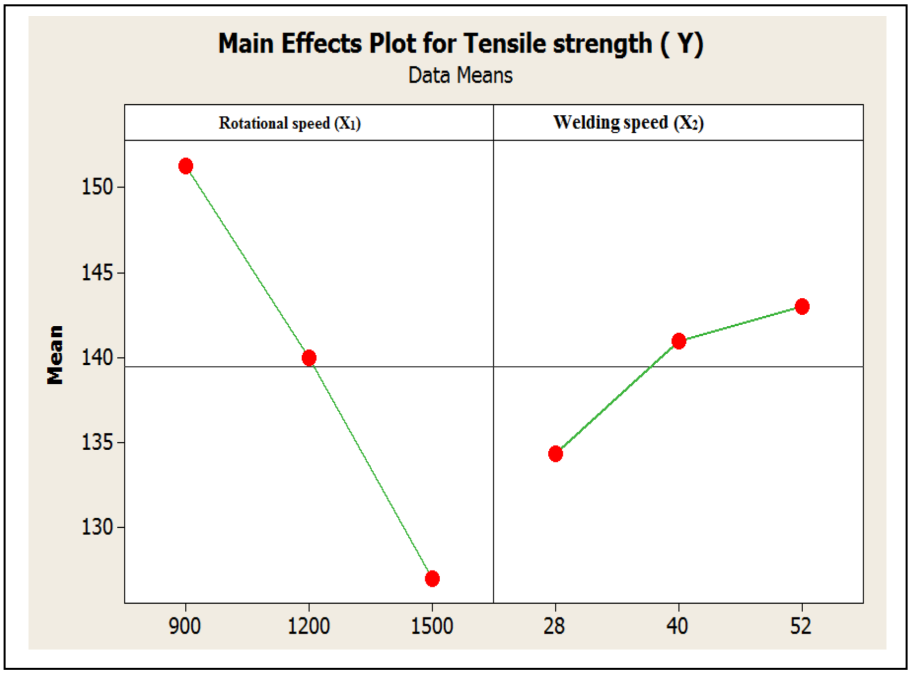


**Figure (8):** Main effect plot of residuals of tensile strength

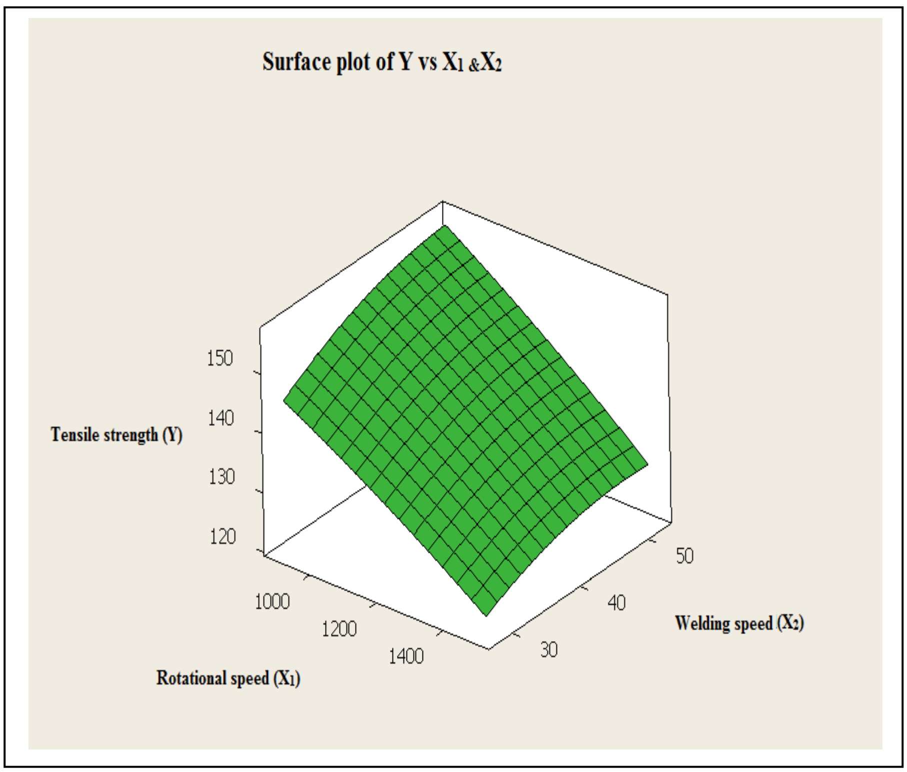


**Figure (9A):** Three-dimension plot of tensile strength

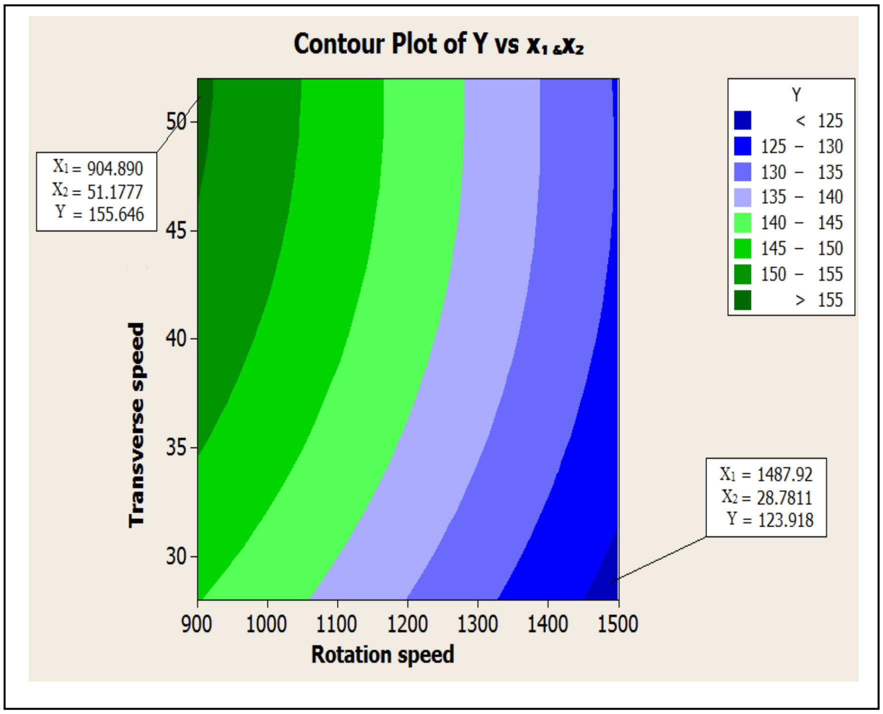


**Figure (9B):** Contour plot of tensile strength

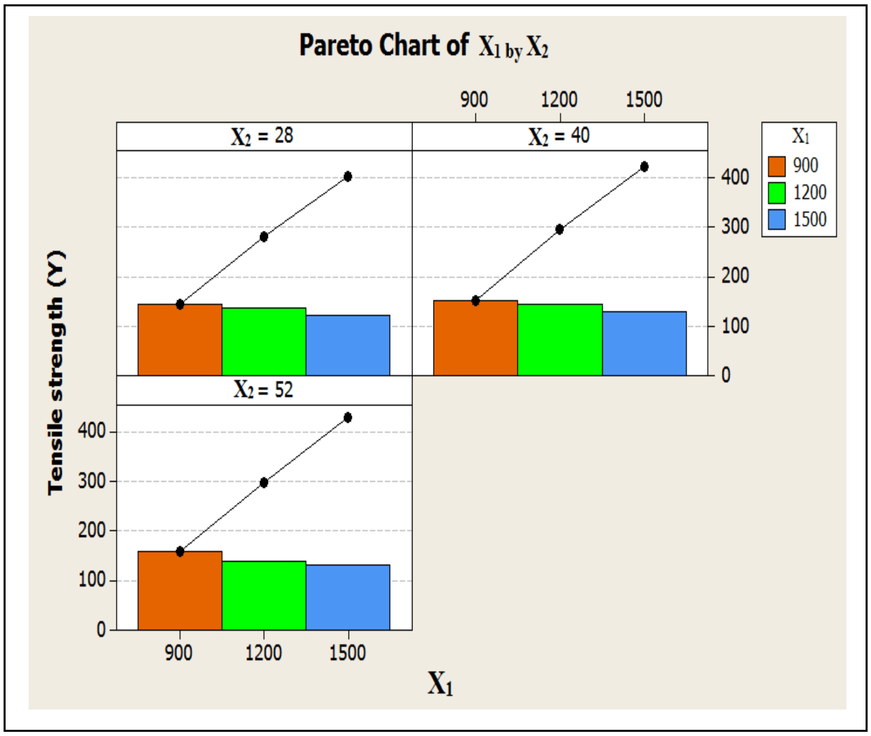


**Figure (10):** Pareto chart for tensile strength