Experimental investigation and Optimization of FSW on Eglin Steel

J Paulmar Pushparaj¹, R Jeremiah¹, D Prabhakaran¹, S Shankaranarayanan², D David², D Billy¹, K Giridharan¹
¹Department of Mechanical Engineering, Easwari Engineering College, Chennai, Tamilnadu, India.
²Department of Mechanical Engineering, Velammal Engineering College, Chennai, Tamil Nadu, India.

* Corresponding author: girimech4305@gmail.com

Abstract. Friction Stir Welding (FSW) is belongs to the solid state welding process. The welding joints were completed by compressive force which can be achieved through the rotational speed of pin. In this process, the welded material was operated below the recrystallization temperature. The heat was formed due to frictional force between the pin and work piece. This experimental investigations have been provided to address the FSW of eglin steel. The Ultimate Tensile Strength (UTS) was the output of the experiment which it was depends on the input factor such as welding speed, feed and pin rotational speed. Taguchi optimization was performed to found the optimal factor. The variance analysis was used to found the contribution factor.

1. Introduction
The friction stir welding has produced better welded joints and it has used in wing structure, fuel tanks, railway tankers, engine chassis and wheel arms. The welding joints consist of thermo mechanically treated zone and heat affected zone. It has produced better welded joints with superior mechanical behaviors and less welding defects. Eglin steel is one of the high strength steel which consist of Fe, C, Mn, Si, Cr, Mo, Ni, W and Cu. The quality of the welding joints has been achieved in FSW of aluminium and its spindle speed was the influential factor [1]. The different FSW parameters were discussed and its parametric effect of tensile strength has been investigated [2-3]. The inconel alloy was the pin material during FSW of aluminium [4]. The substance properties and microstructure has been studied during FSW of aluminium [5-7]. The pin rotation and its shape have been played an essential role in friction stir welding [8]. The FSW parametric effect and its parameters were optimized [9]. The shear stress was produced on the pin surface and it’s found to increase with increasing of rotational speed during FSW of steel [10]. Thermo mechanical behavior and welded joints quality have been studied in steel [11]. The pin rotational speed was produced the effect on weld quality and its worn surfaces have been discussed [12]. The limited pin rotational speed of 200 -500 rpm was maintained for welding of different steel grades [13-14]. The tool wear, weld defects and weld microstructure have been studied in tool steel [15-16]. Traverse speed and tool off set has been considered as the input factors for FSW of steel [17]. Taguchi optimization and variance analysis have been used in friction welding [18-19]. The optimal tensile strength has been found through taguchi optimization in Friction Stir Welding of 6005A-T6 aluminum [20]. The present concept was used to describe the friction stir welding of eglin steel and its factors were optimizing with the help of taguchi method.
2. Experimental method
The FSW H-PRE machine was used to weld the eglin steel. The pin was fabricated by high carbon tool steel. The pin was forced into the work piece when apply the feed to the spindle. FSW of Eglin steel was shown in fig.1. The work piece of eglin steel was rigidly held on the work table through fixture. Frictional force was developed between the pin and the work piece. Slowly, the material was melted below its recrystallization temperature. The pin moves along the welding line of the work piece. The semi solid state molten metal was transferred to the joints through movement of pin. The size of the plates were 150x50x 6mm. The high carbon tool steel pin has better strength and hardness. It was fabricated through CNC and finished through WEDM process.

![Figure 1. FSW of Eglin steel](image)

3. Experimental outcomes and discussion
The ultimate tensile strength was determined through the change of welding speed, rotational speed of the pin and feed. The welding parameters and its design can be decided the quality of the welded joints. The molten metal flow was depends on the welding factors and geometry of the pin. The amount of heat generated was always depends on the rotational speed of the pin. The welding speed depends on rotational speed, penetration of weld and types of welded joint. The experimental setup and work piece of eglin steel was shown in fig.1. The experimental results were shown in table 1. The different factors were considered for the selection of work material such as elevated temperature, wear resistance, co-efficient of thermal expansion and weldability characteristics.

| Exp.No | Pin rotation speed (rpm) | Welding speed (mm/min) | Feed (mm/min) | Weld strength (MPa) |
|--------|--------------------------|------------------------|---------------|--------------------|
| 1      | 900                      | 20                     | 10            | 230                |
| 2      | 900                      | 40                     | 20            | 245                |
3. Taguchi method

The friction welding factors were optimized through taguchi technique. It was one of the high quality system and effective optimization tool. The L9 orthogonal design was applied to minimize the experimental runs. The quality characteristics were depends on the signal to noise ratios. Three main criteria was applied for calculate the performance such as smaller the better, larger the better and nominal the better. For this experimental analysis, larger the better criterion was considered to determine the SN ratio and Means. It was shown in table 2.

| Level | Type       | Pin rotational speed | Welding speed | Feed |
|-------|------------|----------------------|---------------|------|
| 1     | SN ratio   | 47.54                | 49.46         | 50.47|
| 2     |            | 50.61                | 50.51         | 50.10|
| 3     | Delta      | 52.61                | 50.79         | 50.20|
|       | Rank       | 5.07                 | 1.32          | 0.37 |
| 1     | Means      | 238.3                | 304.7         | 345.3|
| 2     |            | 341.3                | 344.3         | 331.7|
| 3     | Delta      | 428.0                | 358.7         | 330.7|
|       | Rank       | 189.7                | 54.0          | 14.7 |

Figure 2. SN ratio effect on UTS

The signal to noise ratio major effect on UTS was shown in fig.2. The peak values were selected as per experimental objective and larger the better condition. The optimal UTS were achieved at pin rotational speed of 1100 rpm, welding speed of 60mm/min and feed of 100mm/min. The contribution of factor and its effect was studied through variance analysis and it’s shown in table 3. The pin rotational speed was the most important factor and it has been provided the maximum effect on tensile strength.
Table 3. Variance analysis for FSW

| Basis             | DF | SS     | MS     | F      | P      | %     |
|-------------------|----|--------|--------|--------|--------|-------|
| Pin rotational speed | 2  | 54093.6| 27046.8| 41.06  | 0.024  | 89.40 |
| Welding speed     | 2  | 4694.9 | 2347.4 | 3.56   | 0.219  | 07.76 |
| Feed              | 2  | 402.9  | 201.4  | 0.31   | 0.766  | 00.67 |
| Error             | 2  | 1317.6 | 658.8  | ---    | ---    | 02.17 |
| Total             | 8  | 60508.9| ---    | ---    | ---    | 100   |

4. Conclusions

- The eglin steel welded joints have been fabricated through FSW process.
- The ultimate tensile strength was measured with the help of input factors.
- The welding factors were optimized through taguchi technique.
- The optimal ultimate tensile strength was achieved at pin rotational speed of 1100 rpm, welding speed of 60mm/min and feed of 100mm/min.
- The rotational speed of pin was the dominant factor on welding strength. It has produced 89.40% of effect on tensile strength.

5. References

[1] Florian Panzer, Martin Werz and Stefan Weihe 2018 Production Engineering 12 667 https://doi.org/10.1007/s11740-018-0834-z
[2] Lakshminarayanan AK, Balasubramanian V and Elangovan K 2009 Int. J. Adv. Manuf. Technol. 40(3–4)286 https://doi.org/10.1007/s00170-007-1325-0
[3] Hattingh DG, Blignault C, van Niekerk TI and James MN 2008 J. Mater. Process. Technol. 203(1–3)46 https://doi.org/10.1016/j.jmatprotec.2007.10.028
[4] Haldar N, Datta S and Kumar R 2018 J.Braz.Soc.Mech.Sci.Eng.40 448 https://doi.org/10.1007/s40430-018-1378-z
[5] Fujii H, Cui L, Maeda M and Nogi K 2006 Mater. Sci. Eng. A 419(1–2) 25 https://doi.org/10.1016/j.msea.2005.11.045
[6] Sakthivel T and Mukhopadhyay J 2007 J.Mater.Sci. 42(19) 8126 https://doi.org/10.1016/s10853-007-1666-y
[7] Balasubramanian V 2008 Mater. Sci. Eng. A 480(1–2) 397 https://doi.org/10.1016/j.msea.2007.07.048
[8] Yasui T, Mizushima H, Tsubaki M, Fujita T and Fukumoto M 2014 Procedia Eng. 81 2092
[9] Jangra KK, Sharma N, Khanna R and Matta D 2016 Proc. Inst. Mech. Eng. Part. L. J. Mater. Des. Appl. 230(2):454
[10] Al-moussawi M, Smith AJ and Young A 2017 Int. J. Adv. Manuf. Technol. 92 341 https://doi.org/10.1007/s00170-017-1047-y
[11] Toumpis AI, Gallawi A, Arbaoui L and Poletz N 2014 Sci.Technol. Weld Join. 19(8) 653 https://doi.org/10.1179/1362171814Y.0000000239
[12] Hasan AF, Bennett CJ and Shipway PH 2015 Mater.Des. 87 1037 https://doi.org/10.1016/j.matdes.2015.08.016
[13] Al-Moussawi M and Smith AJ 2018 Metallogr. Microstruct. Anal. 7 194 https://doi.org/10.1007/s13632-018-0438-1
[14] Toumpis A, Gallawi A, Cater S and McPherson N 2014 Mater. Des. 62 64
[15] Iqbal Z, Bazoune A and Al-Badour F 2019 Arab. J. Sci. Eng. 44 1233
https://doi.org/10.1007/s13369-018-3452-3

[16] Barnes SJ, Bhatti AR, Steuwer A, Johnson R, Altenkirch J and Withers PJ 2012 Metall.
Mater. Trans. A 43(7) 2342 https://doi.org/10.1007/s11661-012-1110-z

[17] Pankaj P, Tiwari A and Biswas P 2020 Weld. World 64 963 https://doi.org/10.1007/s40194-
020-00886-3

[18] Senthilraja R, Sait AN 2015 Mater. Sci. 51 180 https://doi.org/10.1007/s11003-015-9826-8

[19] Naveen Sait A, Aravindan S and Noorul Haq A 2009 Int. J. Adv. Manufact. Technol. 43 581

[20] Ma Z, Li Q and Ma L. 2019 Trans. Indian Inst. Met. 72 1721 https://doi.org/10.1007/s12666-
019-01639-7

Acknowledgments
The authors thank the Department of Mechanical Engineering and his working colleges for their
continuous encouragement to carry out this research work.