Investigation on Boiler Grade Tubes and Tube Plate Using FWTPET Process assisted with PCA

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Abstract. Friction Welding of Tube to Tube Plate using an External Tool (FWTPET) is also used to fuse materials from steel in this study. This inquiry involves the existence and absence of a backrest of the SA 213 boiler-grading tube to the SA 387 tube base in FWTPET. Taguchi L9 orthogonal array and Analysis of Variance (ANOVA) are used to determine the best tensile strength and hardness from the input parameter. The Optimization Part has been performed using Principal Component Analysis (PCA) in the welding process parameter. Moreover, both the welds' interface that can create defect-free welds was found in surface morphological studies. The tensile and hardness properties were evaluated, and the values were tabled so that optimum parameters could be calculated.

Keyword: FWTPET Process; Boiler Grade; SA 213 and SA 387; PCA, GA, Taguchi, ANOVA

1 Introduction

Among some techniques for joining materials, the methodology for joining solid material has a deep adoration in the metallurgical field. The current condition is the mechanism by which the Solid-State Metal Assembly solution ultimately attaches plates to cylinders for various uses such as vehicles, aerospace, and machinery. FWTPET process is the modified friction stir welding process used to join tube and tube plate perpendicularly. This process produces defect-free welds. This process was discovered in 2006, which is a significant step forward in metal joining technology. In 2008, further disputes were patented [1].

In comparison with the fusion welding process, there are various advantages after the invention of this FWTPET process [2]. The use of compression forces results in this method of connecting metal. Excellent weld joints were formed by friction stir welding [3] without any cracks and porosities of solidification. The effective regulation of process parameters contributes to the improvement of mechanical and metallurgical properties [4]. Daniel Das investigates the interference process, using compression strength as output parameters. The unit's rotational speed, which generates friction [5-8], dramatically contributes to its optimum efficiency. Since the author uses many computational methods, the classification of unique welding process types has taken a comparative approach. Most scholars assume from the FSW technique that the critical parameter is the device's rotational speed. Therefore, this study has been achieved by measuring the tensile parameters and optimizing the adjusted UTM configuration's conventional and non-traditional parameters. The better sample was analyzed, and the same samples underwent metallurgical analysis.
2 Materials and Methods

The study analyses sample welded with a cast-iron block backrest using the FWTPET process. The same work is compared during the FWTPET process without the use of a backrest. This technology is used to help the sample during the soldering process. Seamless samples of the hybrid grade Ferritic and Austenitic alloy are used in this research to be dissimilar in the tube and plate's shape. A stand-alone tungsten carbide gear, a high-temperature resistant material, is produced for joining tube and plate. Figure 1 displays the dimensions of the instrument. During the FWTPET process, a cast-iron block in the form of a cube was used to support the experimental sort. The job piece was attached to the vice rig. Figure 2 displays the diagrammatic view of the backrest. A cube-formed block is holed at the middle for a certain depth of 30 mm and a diameter of 20.5 mm.

![Figure 1 Skeleton Diagram of the FWTPET gear with dimensions](image1.png)

The 0 mm, 1 mm, and 2 mm tube variants are designed for processing purposes. The capital joint's power is determined as the tube projection is the most significant parameter [9-15].

![Figure 2 Skeleton diagram of the backrest with dimensions](image2.png)

2.1 Sample Preparation, FWTPET Process, and Microstructure Procedure.

The method FWTPET is a modified Friction Stir process technique. It is a separately updated technique because it was already patentable in 2008. A friction welding machine has a machine vice to carry, and the dimensions shown in Figure 3 are 20.5 mm and 16 mm in the external and internal diameters of the shaft. Besides, the plate measures 50 X 50 and 6 mm wide. The tube and the tube plate are closely fixed perpendicularly. There is a tool pin from Fig 1, which is like a mangrove that supports a knee that restricts the unwanted motion sideways. The pressure is applied by hand; the shoulder rubs the tube plate, which causes friction. The ideal metal bonding was achieved due to extreme plastic deformation. Figure 3 shows that the FWTPET joining strategy uses a different method. Figure 4 indicates that the details of the samples sold using the backrests arrangement [16].
The samples are segmented into four parts for metallurgical investigation. The structure was determined by introducing the piece into the Nital solution after polishing its surface. Methanol and nitric acid are mixed in desirable amounts with Nital. Using UTM (ASTM E1856-13), a tube failure used to evaluate the samples' adhesion strength has been tested with a tensile force. The hardness is tested on the surface of the specimen using Vickers hardness tester (ASTM E92-17). The following values are seen in Table 1 from the exam. Clearance fit is the solid-state metal fitting method that shows the difference between the tube's internal diameter and the pin's outer width in Figure 5.

3 Results and Discussion

3.1 Effects of Tensile Strength and Hardness

Input parameters have welded nine specimens for the orthogonal array. The performance parameter is the intensity of the tractor. Table 1 shows the Tensile Strength validation. The joint capital
force generates at 1300 rpm with a depth of 0.5 mm, and a projection of 1 mm by experimental values produces 806.28 MPa with the support of the backrest. The same parameter builds optimum joining strength of 746.5 MPa without the support of the backrest.

Table 1. Tensile Strength validation of FWTPET sample welded using supporting block

| Ex.No | Tool Speed (rpm) | Tube Projection (mm) | Depth (mm) | Tensile Strength (MPa) |
|-------|------------------|----------------------|------------|------------------------|
| 1     | 705              | 0                    | 0.5        | 597.37                 |
| 2     | 705              | 1                    | 1          | 550.75                 |
| 3     | 705              | 2                    | 1.5        | 591.37                 |
| 4     | 1005             | 0                    | 1          | 665.73                 |
| 5     | 1005             | 1                    | 1.5        | 726.4                  |
| 6     | 1005             | 2                    | 0.5        | 709.25                 |
| 7     | 1305             | 0                    | 1.5        | 719.2                  |
| 8     | 1305             | 1                    | 0.5        | **806.28**             |
| 9     | 1305             | 2                    | 1          | 726.5                  |

Table 1 and Table 2 show the ranking procedure, in which tube forecasts were a significant parameter for the clearance timing system in generating joint power with and without employing backrest.

Table 2. Tensile Strength validation of FWTPET sample welded without employing supporting block

| Ex.No | Tool Speed (rpm) | Tube Projection (mm) | Depth (mm) | Tensile Strength (MPa) |
|-------|------------------|----------------------|------------|------------------------|
| 1     | 705              | 0                    | 0.5        | 597.9                  |
| 2     | 705              | 1                    | 1          | 590.44                 |
| 3     | 705              | 2                    | 1.5        | 582.56                 |
| 4     | 1005             | 0                    | 1          | 558.57                 |
| 5     | 1005             | 1                    | 1.5        | 645.5                  |
| 6     | 1005             | 2                    | 0.5        | 636.3                  |
| 7     | 1305             | 0                    | 1.5        | 662.84                 |
| 8     | 1305             | 1                    | 0.5        | **746.5**              |
| 9     | 1305             | 2                    | 1          | 692.84                 |

Table 3 and Table 4 show the optimum hardness value compared with supporting block and non-supporting block, respectively.

Table 3. Hardness validation of FWTPET sample welded using supporting block

| Ex.No | Tool Speed (rpm) | Tube Projection (mm) | Depth (mm) | Tensile Strength (MPa) |
|-------|------------------|----------------------|------------|------------------------|
| 1     | 705              | 0                    | 0.5        | 256.25                 |
| 2     | 705              | 1                    | 1          | 230.6                  |
| 3     | 705              | 2                    | 1.5        | 242.12                 |
| 4     | 1005             | 0                    | 1          | 264                    |
| 5     | 1005             | 1                    | 1.5        | 283.7                  |
| 6     | 1005             | 2                    | 0.5        | 270                    |
| 7     | 1305             | 0                    | 1.5        | 279                    |
| 8     | 1305             | 1                    | 0.5        | **290**                |
| 9     | 1305             | 2                    | 1          | 284                    |
Table 4. Hardness validation of FWTPET sample welded without employing supporting block

| Ex.No | Tool Speed (rpm) | Tube Projection (mm) | Depth (mm) | Tensile Strength (MPa) |
|-------|-----------------|----------------------|------------|------------------------|
| 1     | 705             | 0                    | 0.5        | 257.8                  |
| 2     | 705             | 1                    | 1          | 240.5                  |
| 3     | 705             | 2                    | 1.5        | 239.5                  |
| 4     | 1005            | 0                    | 1          | 236.69                 |
| 5     | 1005            | 1                    | 1.5        | 259.25                 |
| 6     | 1005            | 2                    | 0.5        | 258.64                 |
| 7     | 1305            | 0                    | 1.5        | 260.8                  |
| 8     | 1305            | 1                    | 0.5        | 287                    |
| 9     | 1305            | 2                    | 1          | 269                    |

3.2 Principal Components Analysis

The tensile strength and hardness levels are validated using principal component analysis (PCA) from this research work. The first principal component value's eigenvalues have been analyzed as 1.9593, and the eigenvalues of the second principal component value are interpreted as 0.0407.

Table 5. Tensile and hardness validation of FWTPET sample welded by employing supporting block using PCA

| Actual Value | Tensile Strength (MPa) | Hardness (Hv) | PCA – Eigen Values Calculated value |
|--------------|------------------------|---------------|-------------------------------------|
|              | Tensile (MPa)          | Hardness (Hv) | MRPI                                |
| 597.37       | 298.59                 | 128.09        | 426.68                              |
| 550.75       | 275.29                 | 115.27        | 390.56                              |
| 591.37       | 295.60                 | 121.02        | 416.62                              |
| 665.73       | 332.76                 | 131.96        | 464.72                              |
| 726.4        | 363.09                 | 141.81        | 504.90                              |
| 709.25       | 354.52                 | 134.96        | 489.48                              |
| 719.2        | 359.49                 | 139.46        | 498.95                              |
| **806.28**   | **403.02**             | **144.96**    | **547.97**                          |
| 726.5        | 363.14                 | 141.96        | 505.10                              |

Table 6. Eigen analysis of the Correlation Matrix

| Eigen value | 1.9593 | 0.0407 |
| Proportion  | 0.980  | 0.020  |
| Cumulative  | 0.980  | 1.000  |

Table 7. Eigenvectors of the correlation matrix

| Variable        | PC1  | PC2  |
|-----------------|------|------|
| Tensile Strength (MPa) | 0.707 | -0.707 |
| Hardness (Hv)     | 0.707 | 0.707  |

The value of proportion for the first and second principal components is 0.980 and 0.020, respectively. Table 5 shows the tensile and hardness validation of the FWTPET sample using PCA with the backrest presence. The Eigen Vector for both Tensile strength and Hardness values are 0.707 each. Table 6 and Table 7 shows the correlation matrix of Eigen Values and Eigen Vectors [17].
Figure 6. Score plot of PCA Values for FWTPET Welded Samples by Employing backing block

Fig 6 and Fig 7 are the graph plot of scores and scree PCA Values for FWTPET Welded Samples by Employing backing block. From the Score plot, the values are not in the same place, and it scatters to a different location. The exact amount has to be omitted during the time of research. From the scree plot, the first principal component's eigenvalue is higher than the second principal component. The graph plot is plotted between the no of principal components and the eigenvalue [18].

Figure 7 Scree plot of PCA Values for FWTPET Welded Samples by Employing backing block

Figure 8 Outlier plot of PCA Values of FWTPET samples.
From Fig 8, it is identified that there is no outlier value. The multi-response performance index is mainly calculated to validate the effects of process parameters and the output using the ranking process. Here the most convincing parameter has been identified at the maximum level of speed (1305 rpm), where are the projection level of the tube is 1 mm and depth has 0.5 mm of the FWTPET sample by the presence of the backing block arrangement [19].

![Main Effects Plot for MRPI](image)

**Figure 9** Main effects of the parameters of MRPI

![Interaction Plot for MRPI](image)

**Figure 10** Interaction of parameters of MRPI

Fig 9 and Fig 10 shows the main effect plot of process parameters and interaction plot of the process parameters of the FWTPET samples by the presence of the supporting block. Table 8 shows the tensile and hardness validation of FWTPET samples without supporting block arrangement [20-22]. The first principal component value's Eigenvalues have been analyzed as 1.9593, and the eigenvalues of the second principal component value are interpreted as 0.0407.

| Actual Value | PCA – Eigen Values Calculated value | MRPI |
|--------------|-------------------------------------|------|
| Tensile Strength (MPa) | Hardness (Hv) | Tensile (MPa) | Hardness (Hv) | |
| 597.9 | 257.8 | 298.86 | 128.86 | 427.72 |
| 590.44 | 240.5 | 295.13 | 120.21 | 415.34 |
| 582.56 | 239.5 | 291.19 | 119.71 | 410.91 |
| 558.57 | 236.69 | 279.20 | 118.31 | 397.51 |
| 645.5 | 259.25 | 322.65 | 129.59 | 452.24 |
| 636.3 | 258.64 | 318.05 | 129.28 | 447.33 |
| 662.84 | 260.8 | 331.32 | 130.36 | 461.68 |
| **746.5** | **287** | **373.14** | **143.46** | **516.59** |
| 692.84 | 269 | 346.32 | 134.46 | 480.77 |
Figure 11. Score plot of PCA Values for FWTPET Welded Samples by the absence of backing block

Fig 11 and Fig 12 are the graph plot of scores and scree PCA Values for FWTPET Welded Samples without employing a backing block. From the Score plot, the values are not in the same place, and it scatters to a different location. The exact amount has to be omitted during the time of research. From the scree plot, the first principal component's eigenvalue is higher than the second principal component. The graph plot is plotted between the no of principal components and the eigenvalue.

Figure 12. Scree plot of PCA Values for FWTPET Welded Samples by the absence of backing block

From Fig 13, it is identified that there is no outlier value. Here the most convincing parameter has been determined at the maximum level of speed (1305 rpm), where are the projection level of the tube is 1 mm and depth have 0.5 mm of the FWTPET sample by the absence of the backing block arrangement.

Figure 13. Outlier plot of PCA Values of FWTPET samples.
Fig 14 and Fig 15 shows the main effect plot of process parameters and interaction plot of the process parameters of the FWTPET samples by the presence of supporting block.

4 Conclusions

In this research work, the FWTPET samples are welded using a backing block, and the values are compared with the pieces without using a backing block.

- By analyzing the effects of parameters of the models welded using supporting block, the most convincing parameters are 1305 rpm, 0.5 mm depth, and 1 mm tube projection, the output tensile strength is 806.28 MPa, and hardness value are 290 Hv.
- By analyzing the effects of the samples welded by the absence of supporting blocks, the most convincing parameters are 1305 rpm, 0.5 mm depth, and 1 mm tube projection; the output tensile strength is 746.5 MPa hardness value is 287 Hv.
- Both Values are validated using Principal Component analysis. The Eigen Vectors of Tensile Strength and Hardness value are 0.707. The first principal component value's eigenvalues have been analyzed as 1.9593 and the eigenvalues of the second principal component value are interpreted as 0.0407 in both cases (With and Without backing block).
- In both cases, the scree plot shows that the first principal components' eigenvalue is greater than the second principal component. From the outlier plot, there are no outlier values.
- By analyzing the MRPI, the main effects plot and interaction show that the optimum tensile and hardness value have been identified using maximum tool rotational speed, optimum tube projection and lower depth of cut.
- The MRPI validation of the sample welded by the presence of the backing block is 547.97, and the MRPI validation of the sample welded by the absence of the backing block is 516.
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