Predict the Tensile Strength of Friction Welded Steel/ASS304L Dissimilar Joints

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Abstract. Due to their availability and unique features, mild steel and ASS 304 L were used for various applications such as shipbuilding, boiler, aircraft, and automotive industries. This alloy is welded by using method of fusion welding. In addition, the strength of welded joints has touched 60 percent of the strength of base materials. However, it is difficult to maintain quality weld when dissimilar steel is joined. Therefore, the choice of electrode, filler wire and other process parameters like current, voltage, shielding gas, etc. requires proper attention. Solid state joining process, friction welding (FW) process is an ideal process to get sound joint. Three major FW parameters such as rotational speed, friction force, and forging force have been used in this work to optimize FW parameters to maximize strength using statistical methodology such as variance analysis and experimental design methodology. From the results, the joint is welded at a rotational speed of 1000 rpm, forging pressure of 30 MPa and friction pressure of 30 MPa

Keywords: Friction welding, Tensile strength, Mild steel, ASS304 L, ANOVA, RSM

1. Introduction
The corrosion resistant steel, particularly austenitic stainless steel (ASS), typically have good resistance to hydrogen embrittlement, weld ability and formability. Although exhibits high strength and ductility. However, it conceived significantly lower strength in hot condition [1]. The 304 grade is the most widely used in the 300series austenitic stainless steels, due to its good toughness at low temperature and corrosion resistance [2, 3]. Low-carbon steel is steel in which carbon in the range of 0.12-2.0 percent is the predominant interstitial alloying constituent. There are a variety of issues that need to be discussed in the arc welding of two different materials, in addition to those associated with welding of identical materials. Second, from a practical point of view, if the melting points of the two materials are too different, it might not be feasible to make a fusion weld, since it is important to have regulated melting simultaneously on both sides of the joint [4-10]. Second, even though this condition is met, if the two materials are metallurgically incompatible, it might not be possible to create an acceptable joint [11-15]. Metallurgical inconsistency can result in uncontrollable welding of metal / HAZ cracking or a welded metal microstructure which cannot provide adequate mechanical or corrosion efficiency, such as containing inappropriate martensite or intermetallic phases[16-22]. Even though it is possible to prevent cracking and deposit sufficient weld metal, there are other potential issues. There will be a band adjacent to the fusion boundary, usually very narrow, within which a steep composition the gradient of the melting point may be present. It is known from previous work that welding of dissimilar materials by friction welding is scarce.
2. Experimental Work
In this experiment, mild steel and ASS304 L were used as parent metal (PM) for friction welding, the chemical properties and characterization of mechanical data of which are shown separately in Table 1 and Table 2 respectively.

Table 1 Chemical composition (% wt.) of parent metals

| Materials   | C     | Si    | Mn    | Ni    | Cr     | Cu     | Fe    |
|-------------|-------|-------|-------|-------|--------|--------|-------|
| MS          | 0.13  | 0.11  | 0.39  | 0.01  | 0.02   | 0.02   | 99.1  |
| ASS304 L    | 0.09  | 0.29  | 8.80  | 0.41  | 14.0   | 1.2    | 74.53 |

Table 2 Characterization mechanical data of parent metal

| Material    | 0.2% yield strength (MPa) | Micro hardness 0.5kg, 15 s (Hv) | % Elongation 50 mm gauge length | Ultimate tensile strength (MPa) |
|-------------|---------------------------|---------------------------------|-------------------------------|------------------------------|
| MS          | 177                       | 139                             | 14                            | 223                          |
| ASS304L     | 649                       | 157                             | 57                            | 383                          |

A 75 mm length and 12 mm diameter rod used for this investigation. The joints were created using an FW machine with numerical control (RV-FW, capacity-30kN, spindle speed-3000 rpm,). In order to find the feasible range of each process parameter, trail runs were performed (Fig.1). Each process parameter was modified from minimum to maximum, while the others were kept constant. The main influencing factors and their levels are shown in Table 3.

![Experimental Work Images]

Fig.1 Working range of friction welding parameters

Table 3 Working window of FW parameters

| Factors                | Levels       |
|------------------------|--------------|
| Rotation speed “rpm”   | -1.682, -1, 0, +1, 1.682 |
| Friction pressure “MPa”| 20, 25, 30, 35, 40 |
| Forging Pressure “MPa” | 20, 25, 30, 35, 40 |
Design expert software was used to limit the number of trails. Three variables were selected to reduce no experimental conditions, five level composite rotatable concept matrixes. The welded joints photograph, as shown in Fig.2.

Where, X is the coded value needed for a variable from X min to X max; X min is the variable's lowest level; and X max is the variable highest.

$$X_i = 2 \left[ X - (X_{max}+X_{min}) \right] / (X_{max}-X_{min})$$  \[1\]

Tensile specimens were manufactured using the ASTM E8M04 standard to test the tensile strength of the joints. UTM was used to measure the strength of each joint, and the average results of the three specimens are shown in Table 4.

### 3. Formulating an empirical relationship

Joining parameters such as friction pressure (F), rotation speed (N), forging pressure (P) are calculated by the tensile strength of the FW 304L with AISI 1020 bimetallic rod.

$$TS = f(P, F, N)$$  \[2\]

The chosen polynomial equation is expressed as

$$TS = b_0 + b_1 (N) + b_2 (F) + b_3 (P) + b_{11} (N^2) + b_{22} (F^2) + b_{33} (P^2) + b_{12} (NF) + b_{13} (NP) + b_{23} (FP)$$  \[3\]

To measure the coefficient of each factor, ANOVA was used. The student t and P test values were determined using ANOVA and shown in Table 5. Values of less than 0.05 for "Prob > F" mean that the terms of the model are important. Important model words are in this case N, F, P, NF, NP, FP, N², F², and P². Values more than 0.1 are negligible in terms of model. By uses of this coefficient, the final equation has been established and is given below.

$$TS = [491.15 + 6.42 (N) + 9.62 (F) - 4.33 (P) + 7.72 (NF) - 1.24 (NP) + 2.0 (FP) - 9.86 (N^2) - 29.15 (F^2) - 17.20 (P^2)] MPa$$  \[4\]

### Table 4 Experimental runs and its response

| Exp.no | Rotation speed (N) "rpm" | Coded value | Forging pressure (P) "MPa" | UTS | Average UTS |
|--------|--------------------------|-------------|---------------------------|-----|-------------|
| 1      | -1                       | -1          | -1                        | 426,430,432 | 429         |
| 2      | 1                        | -1          | -1                        | 428,431,437 | 433         |
| 3      | -1                       | 1           | -1                        | 428,432,436 | 432         |
| 4      | 1                        | 1           | -1                        | 440,460,480 | 460         |
| 5      | -1                       | -1          | 1                         | 418,422,426 | 422         |
| 6      | 1                        | -1          | 1                         | 410,418,414 | 414         |
| 7      | -1                       | 1           | 1                         | 432,420,426 | 426         |
| 8      | 1                        | 1           | 1                         | 450,462,456 | 456         |
| 9      | -1.682                   | 0           | 0                         | 442,462,452 | 452         |
| 10     | 1.682                    | 0           | 0                         | 480,474,462 | 472         |
4. Optimization of FW parameters

To optimize the FW parameters considered in this research, the response surface methodology (RSM) was used. RSM is a series of numerical methods that are important for designing a number of tests, constructing a computational formula, determining the optimal combination of various parameters and presenting the value graphically. [15-16]. Figure 3 shows the perturbation plot for FW joint answer TS. This graph provides the shape of the response and depicts the TS transition as each FW variable shifts from the point of reference.

| Source | SS    | Dof | Mean Square | F Value | p-value  |
|--------|-------|-----|-------------|---------|----------|
| Model  | 18345.4 | 9   | 2038.3      | 436.5   | < 0.0001 significant |
| N      | 562.2 | 1   | 562.3       | 120.4   | < 0.0001 |
| F      | 1266.1 | 1   | 1266.1      | 271.1   | < 0.0001 |
| P      | 259.5 | 1   | 259.6       | 55.6    | < 0.0001 |
| NF     | 480.4 | 1   | 480.5       | 102.9   | < 0.0001 |
| NP     | 12.4  | 1   | 12.5        | 2.6     | 0.132    |
| FP     | 32.0  | 1   | 32.0        | 6.8     | 0.025    |
| N²     | 1404.8 | 1   | 1404.93     | 300.9   | < 0.0001 |
| F²     | 12239.0 | 1 | 12239.11 | 2621.3  | < 0.0001 |
| P²     | 4312.1 | 1   | 4312.28     | 923.6   | < 0.0001 |
| Residual | 46.7 | 10  | 4.67        | 1.47    | Not significant |
| Lack of Fit | 27.7 | 5   | 5.57        | 3.77    | |
| Pure Error | 18.7 | 5   | 3.77       |         | |
| Cor Total | 392.2 | 19 |             |         | |

Fig. 3 Perturbation graph
Fig. 3 shows the halfway tier, and deviation from reference and its response. These contours of response will assistance to predict TS of any region. Peak of the response plot indicates the overall TS achieved. RSM plays a very key role in studying the surface of a result.

![Response surface graphs and contour plots](image)

Fig. 4 Response surface graphs and contour plots

It is obvious from this that when the TS increase to a certain value by increasing the friction strength, rotational speed and forging strength and then lowered. It is also well-known that the initial rise in friction pressure raises the TS to the certain value, and additional friction pressure keeps a TS stable. The maximum achievable TS value is found to be 492.817 MPa. From the RSM plots (Fig.4). A rotational speed of 1041.92 rpm, a friction pressure of 31.08 MPa, and a forging pressure of 29.36 MPa are the corresponding parameters that yield this optimum value. The higher value of the F ratio means the respective levels are more important. It can be inferred from the F ratio value that the key factor leading to the exploitation of TS is the friction pressure, accompanied by the rotational speed and the forging pressure for the range considered in this investigation. Three confirmation experiments with the FW parameters selected independently from the viable working range were performed to validate the established relationship [21]. The average of three measured outcomes was determined as the actual
response. The experimental values, expected values and the variance of FW joints are summarized in Table 6.

Table 6 Validation test results of optimization procedure

| Sl. No | Rotation speed “rpm” | Friction pressure “MPa” | Forging pressure “MPa” | Actual strength “MPa” | Predicted strength “MPa” | % Variation |
|------|----------------------|------------------------|------------------------|------------------------|------------------------|-------------|
| 1    | 900                  | 35                     | 25                     | 431,430,431            | 430.93                | +0.07       |
| 2    | 1200                 | 30                     | 30                     | 493,492,490            | 491.4                 | +0.6        |
| 3    | 1100                 | 25                     | 35                     | 414,410,418            | 414.2                 | -0.20       |

Fig.5 shows the fractograph of tensile tested sample at rotational speed of 1000 rpm, forging pressure of 30 MPa, and frictional pressure of 30 MPa. It reveals shear ridges and populated dimples with varying in size and shape. It implies that large stretch zone was present at the tip of crack. This indicates the mode of fracture was ductile. It may be attributed due to optimal heat input during friction welding of dissimilar steel.

Conclusions

i) Parameters for the friction welding process have been optimized using surface response methodology to achieve optimum joints tensile strength. It is observed that these optimized values are quite similar to the experimental values.

ii) Under rotational speeds of 1000 rpm, frictional pressure of 30 MPa and forging pressure of 30 MPa, a maximum ultimate tensile strength of 492 MPa could be achieved.

iii) The combination of friction welding parameters, i.e., friction pressure of 31.08 MPa / s, forging pressure of 29.36 MPa / s and rotational speed of 1041.92 rev / s yielded maximum tensile strength (492.81 MPa) of dissimilar steel joints.

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