# Effect Of Welding Parameters On Burn-Off Length For Friction Welding Of Inconel 718 And SS 304 For Production Of Bimetal Poppet Exhaust Valve

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***Abstract***— Friction welded joints are formed in the solid state by the heat generated by friction. As the technological advancements take place on daily bases the advancements in automobiles are not out of the race. Any form of boosting for engine power leads to increased temperatures and pressures in the combustion chamber, and much higher exhaust gas temperatures. The exhaust valve, which already has much higher temperatures to deal with than the inlet valve in a naturally aspirated engine, will see its temperature increase still further. So bi-metal valves made of Inconel 718 and SS 304 are under development. Exhaust valves are required to be very precise. They are produced by friction welding. The objective of the following study is to study the effects of the parameters on the on the burn-off of friction welded In conel 718 and SS 304 for production of Bi-metal Poppet Exhaust Valve. The study here discuses the use of Design of Experiments by Taguchi Method. Here Orthogonal Array of $L_{25}$ is used. Using multiple linear Regression and ANOVA effects on the burn-off of welding by Welding Parameters (Rotational Speed, Friction Pressure and Time) are analyzed using MINITAB 17.

**Keywords**: Rotary Friction Welding, SS 304, Inconel 718, Taguchi, ANOVA, MINITAB

## I. INTRODUCTION

The process of friction welding involves two stages. Two components are moved relative to each other under an applied axial load and the heat generated by friction causes a narrow plastic layer to form at the interface. The components are then forged together, usually with an increased axial load and no relative motion. As the weld does not become molten, materials of vastly different properties can be joined by it including different steels, aluminium and steel, aluminium and copper and much more. Other advantages of friction welding include material, machining and weight savings. [1]. in the study below Inconel 718 and SS 304 is friction welded together for the production of bi-metal poppet exhaust valve. In automobile production systems, accuracy and precision are one of most desirable qualities for performance of the engine. Controlled parameters also mean less requirements of machining. Sophisticated Friction welding machines are equipped with sensors to control the Burn Off length and their phases are distributed over Burn off Length. But if your Machine is working on the bases of Time then, Burn Off is not controlled. To control the Burn Off, the behaviour of the parameters on the Burn Off is required to be assessed. This study has to be carried out for the combination of Materials used on the friction welding. The study gives the effects of friction welding parameters such as Speed, Friction Pressure and Time on the Burn-Off Length of the produced weldments.

## II. LITERATURE REVIEW

Both theoretical and experimental studies on these parameters can be seen in various articles. Various researchers such as Vill and Tylecote investigated the parameters that influence the welding quality, the strength of the joint and the hardness of the heat-affected zone (HAZ). [2, 3].

In conel 718 has good weldability by GTAW method but it encounters some problems in conventional joining processes as three main problem areas were encountered and investigated by J Gordine in 1971, which were, Poor penetration during welding, Micro-fissuring in the heat affected zone and poor impact and ductility properties of the weld fusion zone.[4].

C R G Ellis' studies on Continuous Drive Friction Welding of Mild Steel concluded that temperature and the temperature distribution in the HAZ are both pressure and speed dependent for a given burn off setting. Some of very important conclusions they derived were, the equilibrium torque, burn off rate is linearly related with pressure to a substantial extent and approximately inversely related to the speed of rotation. [5] Zhou et al. investigated the influence of joining parameters (rotational speed, frictional time and pressure) on the NTS (Notched Tensile Strength) of dissimilar aluminium-based metal matrix composite MMC/AISI304 stainless steel friction joints. It was observed that frictional pressure and rotational speed have a statistically-significant effect on the NTS values. [6]

S. Vardhan Lalam, G. Madhusudhan Reddy, T. Mohandas, M. Kamaraj and B. S. Murty researched on Continuous drive friction welding of Inconel 718 and EN24 dissimilar metal combination. Nickel based superalloy Inconel 718 and low alloy steel EN24 are welded by continuous drive friction welding in annealed condition and then post-weld heat treated (PWHT).[7]

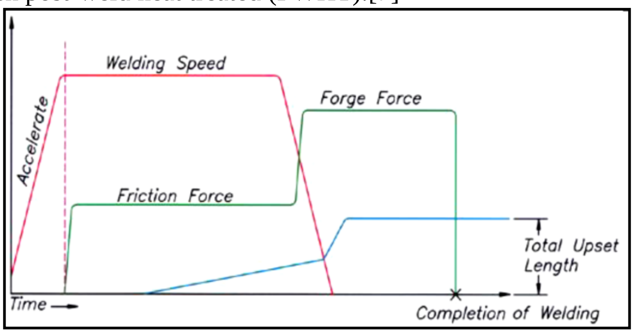


Fig. 1: Rotary Friction Welding Phase Diagram

Eder Paduan Alves ,Francisco Piorino Neto ,Chen Ying An developed Welding of AA1050 aluminium with AISI 304 stainless steel by rotary friction welding process.[8] An attempt was made by R Paventhan, P R

Lakshminarayan and V Balasubramanian to develop an empirical relationship to predict the tensile strength of friction welded AISI 1040 grade medium carbon steel and AISI 304 SS, incorporating the process parameters. Response surface methodology was applied to optimize the friction welding process parameters to attain maximum tensile strength of joint.[9] Hussein Mesmari and Fawzia Krayem studied Mechanical and Microstructure Properties of 304 Stainless Steel Friction Welded Joint. The effect of the individual selected parameters was investigated, as well as the combined effect of interaction of the two parameters was also analysed by Analysis of Means. Weld joints exhibit a comparable strength with the base material with maximum efficiency of 105% that indicates the austenitic stainless steel is quite tolerant with friction welding technique.

The literature suggest that the Speed required for friction welding are generally in the range of 1200 to 2000 RPM, Friction Pressure is in the range of 20MPa to 100 MPa and the Time required is in the range of 2 sec to 30seconds.[7,8].

In this study we have selected combination of Inconel 718 and SS 304 and they are friction welded.

## III. EXPERIMENTAL SETUP

The set-up used in the friction welding experiments is shown in Fig. 2.

The set-up was designed and constructed as continuous drive friction welding. The friction time and friction pressure are controlled manually.

Taguchi's design of experiment is used and Friction pressure, Speed and Friction time are taken as controlled parameters.

$L_{25}$ orthogonal array is used for the specimen generation. The lengths of Specimen before and after the friction welding are noted and by ANOVA the individual effects of the parameters on Burn-Off are found.

The setup is prepared in the workshop at Indus University, Ahmedabad, Gujarat, India.

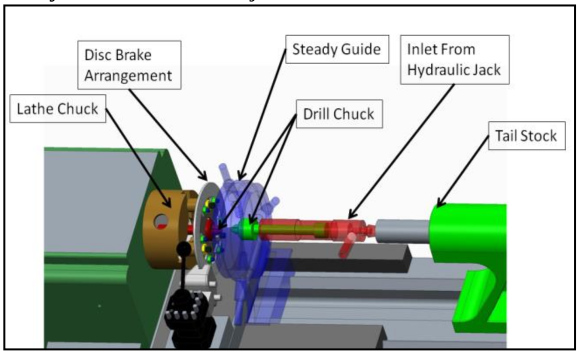


Fig. 2: Setup Layout

The setup is a modified lathe. The lathe is ALL Geared Lathe and is having the range of 40 – 1200 RPM. The pulley ratio was changed to fulfil the speed requirements of the experiment. For pressure application Hydraulic Cylinder is used which is attached to tail stock.

It is the requirement of Continuous drive friction welding that, in the initial condition, one piece is held stationary and other piece is rotated at required speed. Then maintaining that Speed N, pressure is applied (Friction pressure P) for Time T. Then rotation is stopped and the speed is decreased to zero in fraction of second (as shown in Fig 1) and Forging Pressure is applied for some specified time.

For sudden stop arrangement, Disc brake system is attached to the chuck which stops the chuck in less than a second.

TABLE. 1 : CHEMICAL COMPOSITION OF INCONEL 718

| *A.* Component | *B.* Wt % |
|---|---|
| Aluminium- Al | 0.2 - 0.8 |
| Boron- B | Max 0.006 |
| Carbon- C | Max 0.08 |
| Cobalt- Co | Max 1 |
| Chromium- Cr | 17 – 21 |
| Copper- Cu | Max 0.3 |
| Iron- Fe | 17 |
| Manganese- Mn | Max 0.35 |
| Molybdenum- Mo | 2.8 - 3.3 |
| Niobium- Nb | 4.75 - 5.5 |
| Nickel- Ni | 50 – 55 |
| Phosphors- P | Max 0.015 |
| Sulphur- S | Max 0.015 |
| Silicon- Si | Max 0.35 |
| Titanium- Ti | 0.65 - 1.15 |

### *A.* Chemical composition and specimen dimensions

Specimens were machined from Inconel 718 and SS 304. The standard chemical composition of the materials is shown in Tables 1 and Table 2.

Specimen size used in the experiment is
Length: 80-85 mm
Diameter: 6 $^{\pm 0.1}$mm

TABLE. 2 : CHEMICAL COMPOSITION OF INCONEL 718

| **Component** | **Wt %** |
|---|---|
| Carbon- C | Max 0.08 |
| Chromium- Cr | 18 – 20 |
| Iron- Fe | 66.345 – 74 |
| Manganese-Mn | Max 2 |
| Nickel-Ni | 8 - 10.5 |
| Phosphors- P | Max 0.045 |
| Sulphur- S | Max 0.03 |
| Silicon- Si | Max 1 |

### *B.* Selection of welding parameters

According to the Trial and Experiments, the range that can be used is as below.

The Lathe used over here is ALL- Geared Lathe. With help of changing the driving pulley, the speeds that are achieved and useful for our range of experiment are,

- 1178
- 1345
- 1568

- 1800
- 2036

According to the results of trial and experiments we have minimum of 6 Kg/cm2 and maximum of 12 Kg/cm2

The Pressure gauge shown in the Figure 3.7 is attached to the Hydraulic Jack and shows the line pressure of the Hydraulic jack. The pressure measured here is in **kg/cm$^2$** and psi.

- The Diameter of Piston used in hydraulic cylinder is 40mm.X 55 mm
- The Diameter of the Samples is $6^{\pm 0.1}$ mm. So the area will be $28.274^{\pm 0.94}$ mm$^2$
- So for calculating 6kg/cm$^2$ reading on the line pressure gauge
- $A = \pi(20)^2$  A=12.5663 mm$^2$
- Force exerted by Hydraulic Jack = 79.39 Kg (739N) at 6kg/cm$^2$
- Pressure Exerted for the friction welding will be $26.136^{\pm 0.89}$ MPa.

Studies carried out by Johannes Löhe, Marc Lotz, Mark Cannon, and Basil Kouvaritakis in 2013 showed requirement of better control systems such as PID control systems to overcome the non linear nature of the friction welding parameters. The control by PID systems ensures better quality control on friction welding. [10]

The Friction Pressure at the faying surface is shown in the bracket.

- 6 Kg/cm2 (26.136 ±0.89 MPa)
- 7 Kg/cm2 (30.492 ±1.038 MPa)
- 8 Kg/cm2 (34.848 ±1.1836 MPa)
- 9 Kg/cm2 (39.204 ±1.335 MPa)
- 10 Kg/cm2 (43.56 ±1.483 MPa)

And the minimum time required for successful friction welding at 6 kg/cm2 is 8 seconds so Parameters selected for time are

- 8 sec
- 10 sec
- 12 sec
- 14 sec
- 16 sec

Forging Pressure is kept constant to 25-30 Kg/cm$^2$ throughout the experiment and Forging time is also kept constant to 20 Seconds.

## IV. SAMPLE PREPARATION AND DATA COLLECTION

### *A. Sample preparation*

According to the Taguchi's O.A of $L_{25}$ samples were prepared. Their respective length before the welding is collected.

### *B. Data collection*

Collected data is as shown in Table 3.

TABLE. 3: O.A FOR PARAMETERS AND BURN OFF LENGTH

| | Speed RPM | Friction pressure Kg/cm$^2$ | Time Seconds | Burn Of Length (mm) |
|---|---|---|---|---|
| **1** | 1178 | 6 | 8 | 0.48 |
| **2** | 1178 | 7 | 10 | 0.80 |
| **3** | 1178 | 8 | 12 | 1.04 |
| **4** | 1178 | 9 | 14 | 2.24 |
| **5** | 1178 | 10 | 16 | 0.46 |
| **6** | 1345 | 6 | 10 | 0.68 |
| **7** | 1345 | 7 | 12 | 3.08 |
| **8** | 1345 | 8 | 14 | 1.38 |
| **9** | 1345 | 9 | 16 | 2.18 |
| **10** | 1345 | 10 | 8 | 1.57 |
| **11** | 1568 | 6 | 12 | 2.7 |
| **12** | 1568 | 7 | 14 | 4.2 |
| **13** | 1568 | 8 | 16 | 2.6 |
| **14** | 1568 | 9 | 8 | 2.68 |
| **15** | 1568 | 10 | 10 | 2.46 |
| **16** | 1800 | 6 | 14 | 2.52 |
| **17** | 1800 | 7 | 16 | 3 |
| **18** | 1800 | 8 | 8 | 3.72 |
| **19** | 1800 | 9 | 10 | 3.64 |
| **20** | 1800 | 10 | 12 | 1.96 |
| **21** | 2036 | 6 | 16 | 1.42 |
| **22** | 2036 | 7 | 8 | 1.38 |
| **23** | 2036 | 8 | 10 | 2.45 |
| **24** | 2036 | 9 | 12 | 3.9 |
| **25** | 2036 | 10 | 14 | 3.28 |

## V. RESULT AND DISCUSSION

Effect of individual parameters of friction welding such as Speed, Friction Pressure and Time are analysed here by ANOVA. For the analysis Statistical Softwares like MINITAB is used here.

By plotting the response of Speed over Burn-off, we get to know that the as the speed is increased, the Burn Off increases gradually but after speed of 1568 RPM, there are no significant change in length till 1800 RPM and then the burn off starts reducing. The Interval Plot of Burn off Length vs. Speed is shown in Fig 3 Percentage contribution of Speed is 48.84%.

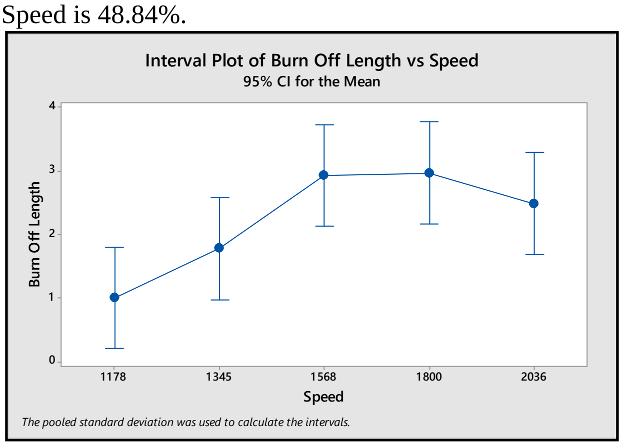


Fig. 3: Interval Plot Of Burn Off Length Vs. Speed

### *A.* Minitab Summary for One-way ANOVA: Burn off Length versus Speed

Method:

| | |
|---|---|
| Null hypothesis | All means are equal |
| Alternative hypothesis | At least one mean is different |
| Significance level | α = 0.05 |

Equal variances were assumed for the analysis.

Factor Information

| Factor | Levels | Values |
|---|---|---|
| Speed | 5 | 1178, 1345, 1568, 1800, 2036 |

Analysis of Variance

| Source | DF | Adj SS | Adj MS | F-Value | P Value |
|---|---|---|---|---|---|
| Speed | 4 | 14.02 | 3.5059 | 4.77 | 0.007 |
| Error | 20 | 14.69 | 0.7344 | | |
| Total | 24 | 28.713 | | | |

Model Summary

| S | R-sq | R-sq(adj) | R-sq(pred) |
|---|---|---|---|
| 0.856997 | 48.84% | 38.61% | 20.06% |

After Plotting the Interval Plot of Burn Off length vs. Friction Pressure ,it is clear that the variation if the friction pressure is not a major affecting parameter as its variation is independent. The burn off length is increased in the beginning and then it declines after 7Kg/cm$^2$ Pressure, then it is again increased when 9Kg/cm$^2$ is achieved and then it is again decreasing. The percentage contribution of friction pressure is **18.9%.**

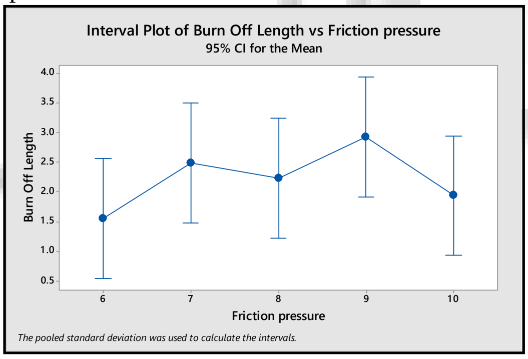


Fig. 4: Interval Plot Of Burn Off Length Vs. Friction Pressure

### *B.* Minitab Summary for One-way ANOVA: Burn off Length versus Friction pressure

Method

| | |
|---|---|
| Null hypothesis | All means are equal |
| Alternative hypothesis | At least one mean is different |
| Significance level | α = 0.05 |

Equal variances were assumed for the analysis.

Factor Information

| Factor | Levels | Values |
|---|---|---|
| Friction pressure | 5 | 6, 7, 8, 9, 10 |

Analysis of Variance

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Friction pressure | 4 | 5.427 | 1.357 | 1.17 | 0.356 |
| Error | 20 | 23.285 | 1.164 | | |
| Total | 24 | 28.713 | | | |

Model Summary

| S | R-sq | R-sq(adj) | R-sq(pred) |
|---|---|---|---|
| 1.07901 | 18.90% | 2.68% | 0.00% |

Plot from Fig 5, shows that as the time is increased, there is increase in the burn off length and the increase is progressive. At 14 seconds, the Burn off is maximum but after further increasing the time, dramatically Burn-Off is reduced. Percentage Contribution by Time for Burn Off length is very less so this is considered as Noise for predicting the response so R-sq(pred) comes out to be zero

### *C.* Minitab Summary for One-way ANOVA: Burn off Length versus Time

Method

| | |
|---|---|
| Null hypothesis | All means are equal |
| Alternative hypothesis | At least one mean is different |
| Significance level | α = 0.05 |

Equal variances were assumed for the analysis.

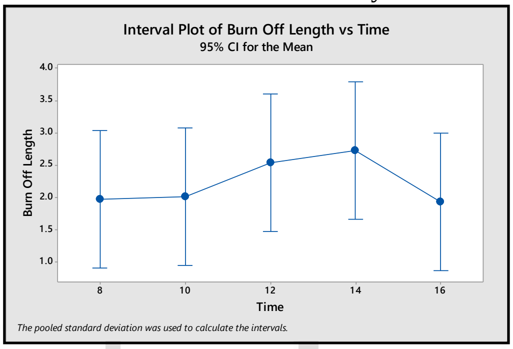


Fig. 5: Interval Plot Of Burn Off Length Vs. Time

Factor Information

| Factor | Levels | Values |
|---|---|---|
| Time | 5 | 8, 10, 12, 14, 16 |

Analysis of Variance

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Time | 4 | 2.732 | 0.6829 | 0.53 | 0.718 |
| Error | 20 | 25.981 | 1.2990 | | |
| Total | 24 | 28.713 | | | |

Model Summary

| S | R-sq | R-sq(adj) | R-sq(pred) |
|---|---|---|---|
| 1.13976 | 9.51% | 0.00% | 0.00% |

## VI. CONCLUSIONS AND FUTURE SCOPE

The experiment concluded that the **Speed** is the main factor that is affecting the Burn off Length. Other parameters such as Friction Pressure and Time are contributing but not at a large scale so they can be neglected or can be taken as noise.

The results can be very helpful for generating FEA Models for friction welding. Other properties of Bi-metal Poppet Exhaust valves such as tensile strength, toughness, hardness and fatigue properties can be analyzed and can be used for Bi-metal Production of Poppet Exhaust.

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## REFERENCES

[1] "History of Friction welding ", The Journal of Production
[2] Engineer , Page no 78 , September 1983
[3] V.I. Vill, Friction Welding of Metals, AWS, New York, 1962.
[4] R.Y. Tylecote, The Solid Phase Welding of Metals, Edward Arnold Ltd., London, 1968, pp. 1–50.
[5] J. Gordine , "Some Problems in Welding Inconel 718", Welding Research Supplement, 1971, Page 480-484
[6] C R G Ellis , "Continuous Drive Friction Welding of Mild Steel", Welding Research Supplement, 1972, Page 183-197
[7] Zhou Y, Li Z, Hu L and Fuji A, "Mechanical properties of particulate MMC/AISI 304 friction joints", JISIJ International, 1995 Vol 35 Issue 10 Page 1315–1321
[8] S. Vardhan Lalam, G. Madhusudhan Reddy, T. Mohandas, M. Kamaraj and B. S. Murty, "Continuous drive friction welding of Inconel 718 and EN24 dissimilar metal combination", Materials Science and Technology ,2009 Vol 25 No 7, Page 851-861
[9] Eder Paduan Alves, Francisco Piorino Neto and Chen Ying An, "Welding of AA1050 aluminum with AISI 304 stainless steel by Rotary Friction Welding Process", Journal of Aerospace Technology Manag., 2010, Vol.2 No.3, Page 301-306
[10] R Paventhan, P R Laksminarayanan and V. Balasubramanian, "Optimization of friction welding process parameter for joining Carbon steel and Stainless steel", Journal Of Iron And Steel Research International, 2012, Vol 19 Issue 1, Page 66-71
[11] Johannes Lohe, Marc Lotz, Mark Cannon, and Basil Kouvaritakis, "Application of Optimal Control Algorithm to Inertia Friction Welding Process", IEEE transactions on control systems technology, 2013,Vol. 21, No. 3, Page 891-898