Optimization of Friction Stir Welding Process Parameters for Welding Aluminum Alloys

Shaikh Mohammed Shakil
PG Student
Department of Mechanical Engineering
Government Engineering College, Dahod

Prof. Yagnesh B Chauhan
Professor
Department of Mechanical Engineering
Government Engineering College, Dahod

Abstract

In this dissertation work investigation on machining parametric optimization of friction stir welding is carried out for joining of dissimilar aluminum alloys. This investigation is carried out to for joining of a heat treating aluminium with a non heat treating aluminium alloys. In this study, the variable parameters, that affect much, are taken as input parameters. They are Tool Rotational speed, traverse speed and tilt angle output parameters are as hardness, tensile strength, and yield strength. Work material is taken as AA6061 T6 and AA2024 T0. All the experiments will be conducted on Vertical Machining Centre (VMC). Taguchi method based on L9(33) orthogonal array design of experiment is used and depending upon the design, total 9 experiments are to be performed; The output parameters are measured with the accurate method. Hardness measure in vicker's hardness tester and tensile stress and yield stress are measured using universal bending machine. Second part of the dissertation work focuses on analysis of results and multi response Optimization. Analysis is done using MINITAB 15 statistical software specifically used for design of experiment analysis. For the verification of the optimized results gained by MINITAB 17 software. The grey relational analysis is used multi response optimization, and regression mathematical model, used for the statistical analysis. All the methods optimized the same level.

Keywords: Friction Stir Welding, Rotational Speed, Traverse Speed, Tilt Angle, Tensile Strength, Yield Strength, Hardness

I. INTRODUCTION

The difficulty of making high-strength, fatigue and fracture resistant welds in aerospace aluminium alloys, such as highly alloyed 2XXX and 7XXX series, has long inhibited the wide use of welding for joining aerospace structures. These aluminium alloys are generally classified as non-weld able because of the poor solidification microstructure and porosity in the fusion zone. Also, the loss in mechanical properties as compared to the base material is very significant. These factors make the joining of these alloys by conventional welding processes unattractive. Some aluminium alloys can be resistance welded, but the surface preparation is expensive, with surface oxide being a major problem. Friction stir welding (FSW) was invented at The Welding Institute (TWI) of UK in 1991 as a solid-state joining technique, and it was initially applied to aluminium alloys. The basic concept of FSW is remarkably simple. A non-consumable rotating tool with a specially designed pin and shoulder is inserted into the abutting edges of sheets or plates to be joined and traversed along the line of joint

A. Friction stir Welding

Friction stir welding is the solid state metal joining process in this process two metals are join using a third body which is also in a solid state. The FSW tool is the solid state heat treated hard metal which is passed through the two edge of the base metal to be joined together at a specific rotational speed, traverse speed, axial force and tilt angle. There has been a wide range of metal which has been friction stir welded and the advancing technology has widen to improve weld quality and weld ability of a variety of dissimilar metal are been discovered.

Fig 1 FSW Set up

The tool serves two primary functions: (a) heating of work piece, and (b) movement of material to produce the joint. The heating is accomplished by friction between the tool and the work piece and plastic deformation of work piece. The localized heating softens the material around the pin and combination of tool rotation and translation leads to movement of material from the front of the pin to the back of the pin. As a result of this process a joint is produced in 'solid state'. Because of various geometrical features of the tool, the material movement around the pin can be quite complex. During FSW process, the material undergoes intense plastic deformation at elevated temperature, resulting in generation of fine and equiaxed recrystallized grains.

B. Welding parameter

1) Angle of Tool Tilt and Plunge Depth:-

The angle of tilt around 2-4 degrees is usually adopted in various FSW processes. It helps in a proper forging process. The plunge depth into the work piece increases the pressure below the tool and provides good forging of material behind the tool.

2) Tool Traverse and Rotational Speeds:-

From various studies it has been concluded that by increasing the rotation speed of the tool and decreasing the traverse speed of the tool the temperature in the weld region increases. Adequate temperature is necessary because if the material is too cold then voids may form and if the material is too hot then it could lead to defects due to the liquation of low-melting point phases.

II. LITERATURE REVIEW ON FRICTION STIR WELDING

Bisadi et al.[4], in friction stir lap welding of 2.5 mm-thick AA 5083 to 3 mm-thick commercially pure copper sheets, claimed, in good agreement with that extreme welding temperatures give rise to defective joints. The authors observed channel-like defects near the sheets interface, for very low temperatures, and cavities at the interface of stirred aluminium particles and the copper, for high welding temperatures. Higher aluminium diffusion was observed in friction stir welding of aluminium which makes that aluminium particles are forced in to the copper sheet and after quenching some cavities are formed at the interface of the particles and the copper matrix. Besides the high temperatures, the different melting temperatures and contraction coefficients of both materials are pointed by the authors as the main factors on the basis of this type of defect. It was also reported that for the range of welds tested, the hardness values of the stirred aluminium alloy were considerably lower than that of the aluminium base material, contrary to the stirred copper hardness which was in over-match relative to the base material.

For example previously Saeid et al made lap joints ofAA1060 and copper sheets 4 and 3 mm thick respectively by a tool made of H13 with shoulder diameter of 15 mm and a cylindrical threaded pin 15mm in diameter and 6.5 mm in length. The tool tilt angle was 3^{o}. Also position control was used for adjusting the normal load to the top sheet surface and the insert depth of tool shoulder was 0.2 mm. The rotational speeds varied from 750 to 1500 rpm and the welding speeds ranged from 30 to 375 mm/min

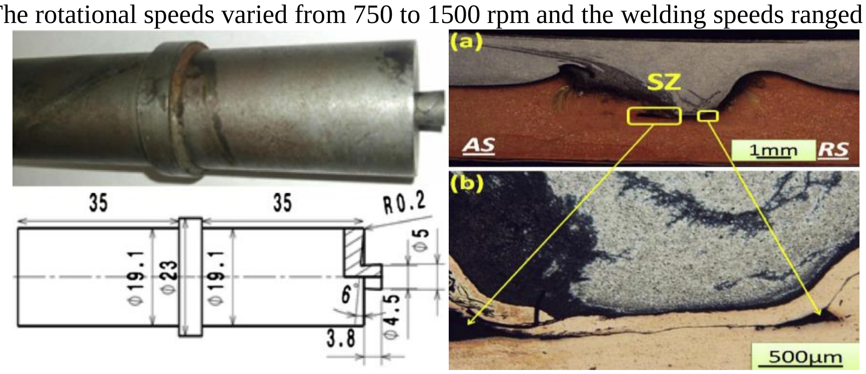


Fig. 2: The FSW tool used for all the welding processes.(a) Macrostructure and (b) some channel defects on the sheets interfaces in specimen.

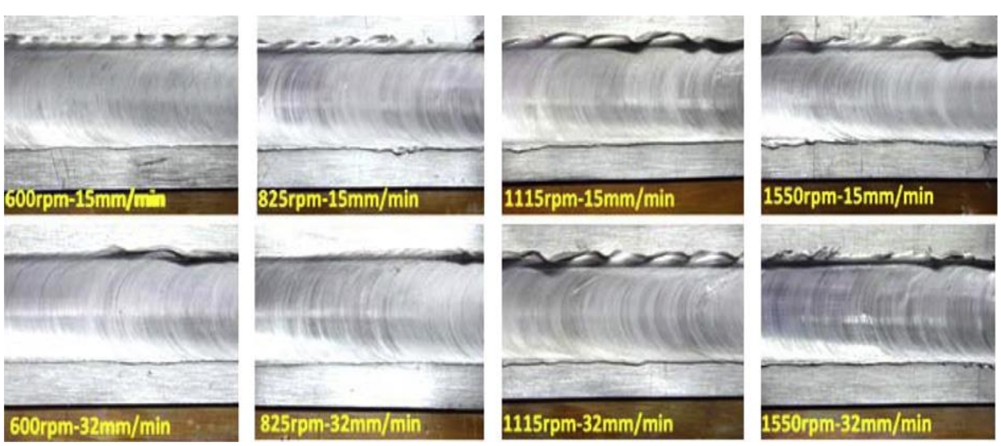


Fig. 3: Lap joint surfaces welded in different conditions.

Leitao et al [5] have already addressed the influence of the markedly different mechanical behaviours of the AA5083 and the AA6082 aluminium alloys, at high temperature and strain rates, on the friction stir weld ability of both alloys. According to these authors, whereas the AA6082 aluminium alloy experiences strong softening with plastic deformation at increasing temperatures, which is traduced by a strong decrease of the flow stresses of the material with plastic deformation, the AA5083 alloy presents, at high temperatures, steady flow stress behaviour. As a result of this, under the same axial load during FSW, the higher thermal softening experienced by the AA6082 alloy led to further submerging of the tool during welding, relative to the 5083 alloy, which resulted in the strong deepening and massive flash formation observed at the surface of the weld.
For the AA6082

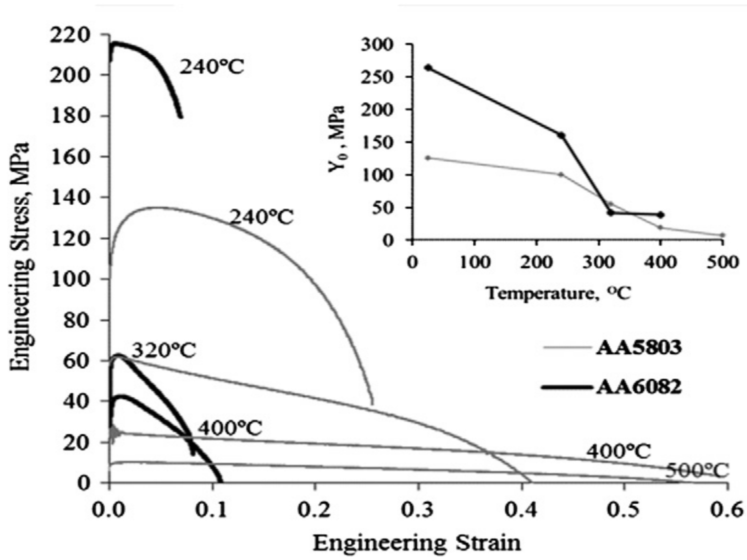


Fig. 4: Engineering tensile stress–strain curves and evolution of base materials yield stress with temperature.

The influence of the high temperature plastic behaviour of two aluminium alloys, very popular in welding construction, on friction stir weld ability, was analyzed in this work. It was found that theAA6082 alloy, which according to the base materials mechanical characterization results, is sensitive to intense flow softening during high temperature plastic deformation, displays good weld ability in FSW. For the AA5083 alloy, which according to the base materials mechanical characterization results, displays steady flow behaviour at increasing temperatures, very poor weld ability was registered under the same welding conditions of the AA6082-T6 alloy. This behaviour results from the strong influence of the plastic properties of the base materials, at high temperatures, on material flow during welding, as well as on contact conditions at the tool work piece interface. The very important influence of base material plastic properties on friction stir weld ability depicted in this work was never addressed before in FSW literature, which traditionally relates material flow during welding, as well as welds morphology and defects, with tool geometry and/or processing conditions.

Galvao et al [6] were worked on a heat-treatable (AA6082) and a non-heat treatable (AA5083) aluminium alloys. They were friction stir lap welded to copper using the same welding parameters. According to the aluminium alloy type, after conducted experiment they found internal defects, resulting from ineffective materials mixing, were detected for the AA 5083/copper welds, a relatively uniform material mixing was detected in the AA 6082/copper welds. They used Micro-hardness testing and XRD analysis which showed important differences in micro structural evolution for both types of welds. They found that AA 5083/copper-DHP welds has excellent surface finishing, but highly defective Al/Cu interfaces, without any signs of base materials interaction, the AA 6082/copper- DHP welds displayed poor surface properties, but strong base materials mixing in the stirred zone.

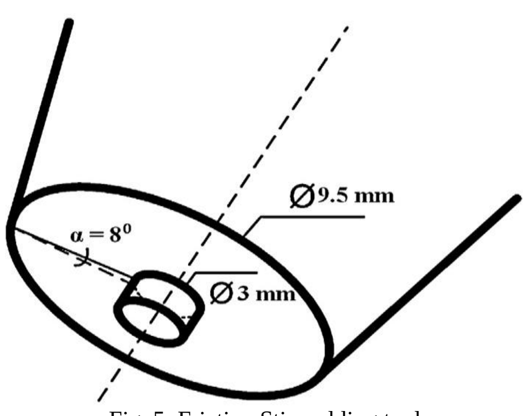


Fig. 5: Friction Stir welding tool

C.Devanathan et al[8] were worked on friction stir weld ability of 5% SiC particulate aluminum matrix cast composite using TiAlN coated tool and investigation of effect of process parameters such as tool rotation speed, traverse speed, and axial force on ultimate tensile strength. The result showed that there was no noticeable tool wear, only aluminum particles were deposited on the tool pin. They observed that the optimal FSW process parameter combinations were spindle speed at 1200 rpm, traverse speed at 40 mm/ min and axial load at 8 KN. It was found that the axial force had the maximum contribution of 35% followed by traverse speed and spindle speed of 25% and 12% respectively. The effect of process parameters were evaluated using ANOVA and S/N ratio of robust design. It was observed that the axial force exhibits more influence on tensile strength followed by traverse speed and tool rotation speed.

- ANOVA: Analysis of Variance

The Analysis of Variance popularly known as the ANOVA can be used to identify the process parameters that are statistically significant which affect the tensile strength of the welded joints produced by FSW. ANOVA was performed using Minitab 16 statistical software. The results of ANOVA are summarized in the table below

Table – 1
ANOVA table

Source Of Variation	D.o.F	Sum Of Squares	Mean Sum Of Squares	F	P	Percentage Of Contribution
RS	2	6.07	3.03	0.45	0.687	12.2
TS	2	12.8	6.41	0.96	0.510	25.8
AF	2	17.48	8.74	1.31	0.433	35.16
ERRORS	2	13.33	6.67			26.85
TOTAL	8	49.69				

In addition, the F –test named after Fisher can also be used to determine which process parameter has a significant effect on the tensile strength. Usually the process parameters have a significant effect on the quality characteristics when F is large

The results of ANOVA indicate that the considered process parameters are highly significant factors affecting the tensile strength of FSW joints in the order of axial force, traverse speed and tool rotation speed. The percentage of contribution is the portion of the total variation observed in the experiment attributed to each significant factors and/or interaction which is reflected. The percentage of contribution is a function of the sum of squares for each significant item it indicates the relative power of a factor to reduce the variation. If the factor levels are controlled precisely, then the total variation could be reduced by the amount indicated by the percentage of contribution

K.Venkata Kalyani et al [9] This paper deals with friction stir welding of AA6061-T6 Aluminium Alloy by using H13 tool at different rotational speeds and welding feeds and pin diameters. Experiments were conducted according to L9 orthogonal array which was suggested by Taguchi. Optimum parameters for optimum tensile strength, hardness and ductility were found with the help of s/n ratios. Therefore optimization of input process parameter is required to achieve good quality of welding. In this experiment the effect of process parameters on welded joint was studied and optimizes the parameter by using Taguchi method for tensile strength, hardness, ductility. Assign the rank to each factor which are having more influence on the mean tensile strength, hardness and ductility

- Selection of Orthogonal Array

Based on the number of factors and levels a suitable Taguchi orthogonal array for the experiment is selected by using MINITAB 16 statistical software. Since there are three factors having three levels each, L9 OA is chosen as shown in table

Table - 2
Experimental results for tensile strength, hardness and S/N ratios of FSW butt welds

Runs	N	F	D	Tensile strength (N/mm^2)	S/N Ratio	Hardness (RHN)	S/N Ratio
1	1120	25	2.5	112.65	41.03	46	33.25
2	1120	40	4	141.47	43.01	49.125	33.82
3	1120	50	6	129.83	42.27	52	34.32
4	1400	25	4	151.68	43.62	45	33.06
5	1400	40	6	157.66	43.95	45.125	33.08
6	1400	50	2.5	123.33	41.82	56.75	35.07
7	1800	25	6	153.83	43.74	47.125	33.46
8	1800	40	2.5	115.57	41.26	47.875	33.60
9	1800	50	4	136.78	42.72	49.25	33.84

Larger is better for tensile strength and hardness

SNs $= - 10_{\log 10}(1/k \sum^{k}_{r=1} (1/y^2 i_r))$

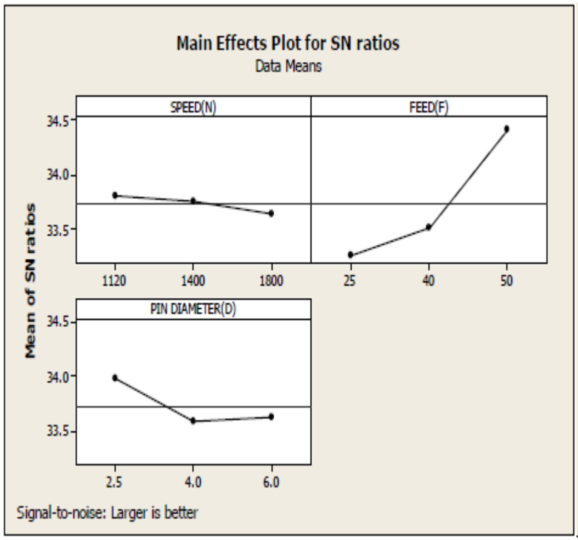


Fig. 6: Graphical results for tensile strength

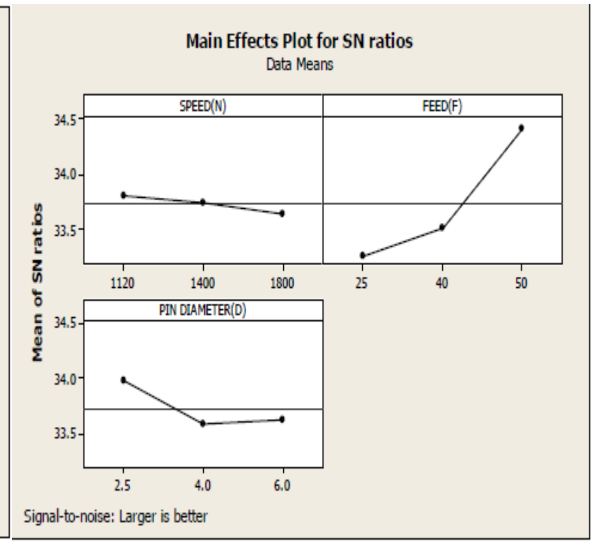


Fig. 7: Graphical results for hardness

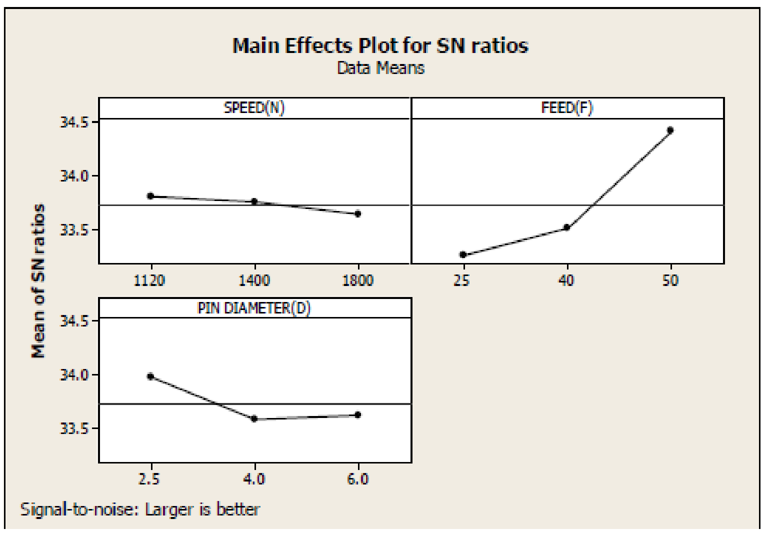
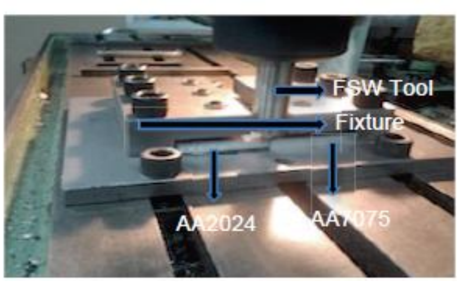


Fig. 8: Graphical results for ductility

Avinash P et al [10] to investigate the mechanical and structural properties of AA7075 T6 and AA2024 T3 dissimilar aluminium alloys, with thickness ratio 1.3, since both AA2024 T3 and AA7075 T6 are not weld able by fusion welding process, FSW process is used to weld both of these dissimilar alloys. Defect-free, tailor weld blanks were produced on the plates of AA7075 and AA2024 T3 having thickness of 6.5mm and 5mm respectively. The process parameters employed in this study include the tool rotation and travel speeds. The FSW tool employed in this study was made using AISI H13 tempered steel with square pin profile having pin diameter of 5mm, concavity at pin start of 1mm and pin length of 4.85mm. The welded plates have been characterized for their mechanical and metallurgical properties. The effects of tool rotational speed and the welding speed on the joint performance were discussed. Experimental result shows a sound weld has been produced at medium rotational speed (1000rpm) and lower travel speed (80mm/min), uniform weldments



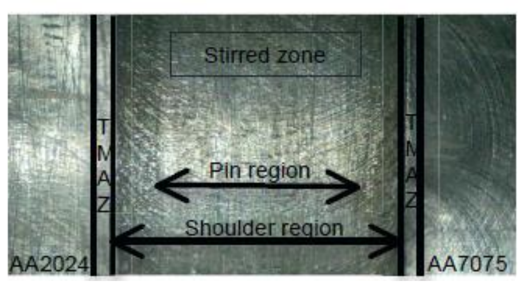


Fig. 9(a) FSW process carried using conventional milling machines with the aid of specially designed fixture Fig. 9(b): Macrograph of the welded sample

M. Dehghani et al [11] were conducted experiment on Joints of Al5186 to mild steel by using friction stir welding (FSW) technique. They investigated the effects of various FSW parameters such as tool traverse speed, plunge depth, tilt angle and tool pin geometry on the formation of intermetallic compounds (IMCs), tunnel formation and tensile strength of joints. They found that At low welding speeds due to the formation of thick IMC's the tensile strength of joints was very poor and at low welding speeds the tunnel defect was formed. As the welding speed increased, the IMCs decreased and the joint exhibited higher tensile strength. They showed that the tunnel defect could not be avoided by using cylindrical 4mm and 3mm pin diameter and by using a standard threaded M3tool pin the tunnel was avoided and a bell shape nugget formed. They revealed that the tensile strength of the joint increased to 90%ofaluminum base alloy strength and at higher welding speed and lower tool plunge depth, the joint strength decreased due to lack of bonding between aluminum and steel.

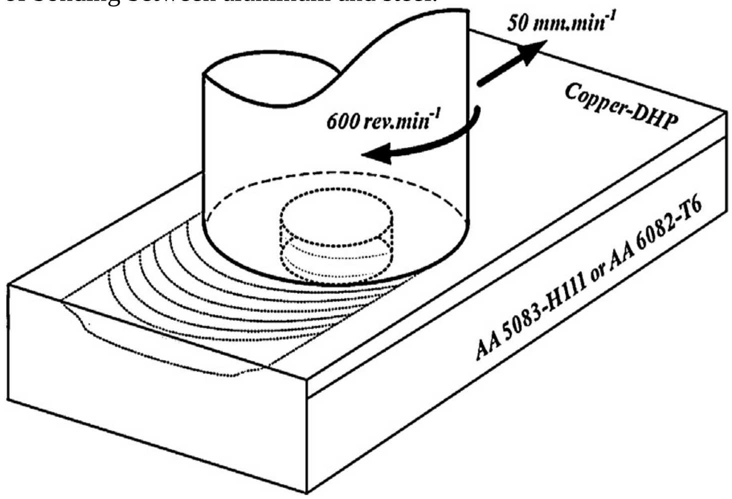


Fig 10: Schematic representation of Al/Cu friction stirs welding.

After welding, a qualitative macroscopic inspection of the weld surfaces was performed by means of visual inspection. Transverse cross-sectioning of the welds was performed for metallographic analysis. The samples were prepared according to standard metallographic practice and differentially etched in order to enable the analysis of the micro structural transformation induced by welding. Metallographic analysis was performed using optical microscopy, in ZEISS 100 HD equipment. The microstructure of some selected welds was also analysed by transmission electron microscopy (TEM) and electron backscatter diffraction (EBSD) in a FEI Tecnai G2 S-Twin and a FEI Quanta 400FEG ESEM/EDAX Genesis X4M microscopes, respectively. Micro hardness measurements were performed using a Shimadzu Micro hardness Tester, with 200 g load and 15 s holding time

III. CONCLUSION

As per review of papers, we can see that many of researchers have worked on joining of similar metal but very few works has been carried out on new advance dissimilar metal. Dissimilar metal joining process using friction stir welding is very difficult to achieve because of different co-efficient of heat and the base metal chemical composition and their property make it difficult to choose a proper welding parameters like rotational speed, traverse speed, axial force and tilt angle which plays a vital role in improving the weld quality. There is very little awareness about this technology i want to improve the quality of the weld strength and also want to prove that this technology can give a very good quality dissimilar joint fabrication.

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