RESEARCH ARTICLE OPEN ACCESS

Analysis of Friction Stir Welding of Aluminum Alloys and Optimization of Welding Parameters for Maximum Tensile Strength

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Abstract
The Friction Stir Welding (FSW) process is an innovative technique to join metals in the plastic state thus not reaching the liquid state as it happen in traditional welding processes.
This feature of the FSW proved that a modification can be done on the fatigue behavior and strength of the welding joints so, some of the leading companies to adopted the process for the manufacturing of Automotive, Locomotive, Shipping & Aerospace.
The FSW is a variant of the linear friction welding process in which the material is being welded without bulk melting. The FSW parameters such as tool Rotational speed, Welding speed, Axial Force, Tool tilt angle, Welding Tool Shoulder Diameter, and Welded Plate thickness play a major role in determining the properties like Tensile strength, hardness, residual stress, HAZ etc. of the joints.
Our objective is to optimize the welding parameters to achieve Max. Tensile Strength of Aluminium Alloys (especially on AA-2xxx, AA-5xxx) under FSW.
We only wish to optimize (by Taguchi and ANOVA method) with three variable input parameters (Rotational speed in rpm, Translation speed in mm/min & Axial force in KN) considering a cylindrical pin.
Keywords: - FSW, Aluminium Alloys, Tensile Strength.

I. Introduction:-

Aluminum is a chemical element with symbol Al and atomic number 13. It is a silvery white, soft, durable, lightweight, ductile and malleable metal . Aluminum serves as a good reflector of visible light and an excellent reflector of medium and far infrared radiation. Aluminum alloys have yield strengths ranging from 200 MPa to 600 MPa. Aluminum has about one-third the density and stiffness of steel. It is easily machined, cast, drawn and extruded.
Aluminum is a good thermal and electrical conductor. Aluminum is capable of being a superconductor. Aluminum is a good thermal and electrical conductor. Aluminum is capable of being a superconductor. It is having excellent corrosion resistance properties also.
Friction stir welding is one of the new entrants to the solid state joining techniques, which have made remarkable progress in welding technology. Friction Stir Welding (FSW) is a new joining process invented by The Welding Institute (TWI) in England and patented in 1991 and is essentially a solid state joining process, widely used for the welding of light and difficult-to-weld metals and their alloys like aluminum, magnesium, copper etc.
Recently, its applications have been extended to the welding of high melting point materials such as various types of steels, Ti alloys, Ni-based super alloys, the welding of metal matrix composites and polythene. Friction stir welding is being used in various engineering applications, which require the joining of dissimilar material combinations and which are not viable using conventional fusion welding techniques. With recent developments in technology of friction stir welding, it is now possible to carry out dissimilar welding of various types of steels with alloys of aluminum, magnesium, copper, titanium and also other alloy combinations. Moreover, workpieces in the form of plates, sheets and hollow pipes can be welded by this method. Over a period of time developments in friction stir welding have led to different variants like friction stir processing, friction stir spot welding, friction stir channeling etc. Thus, it can be said that friction stir welding and its variants have brought a revolution in the field of solid state joining technology.

Why selected Aluminium Alloys over the Steel:-

- ✓ Aluminium Alloys are soft, durable, lightweight, ductile and malleable metal compare to steel.
- ✓ Some aluminum alloys are stronger than steel.
- ✓ Lighter & Stiffer compared to steel.
- ✓ Less corrosive than steel.

II. Friction Stir Welding Process :-

The Process Friction Stir Welding (FSW) is a process in which a rotating cylindrical tool connected with a shoulder and a profiled pin (may be conical or cylindrical with thread) is plunged into the adjoining plates to be joined and moved along the line of the joint.

The plates are tightly clamped on to the backing plate of the FSW equipment to prevent them from coming apart during welding. A cylindrical tool rotating at high speed is slowly plunged into the plate material, until the shoulder of the tool touches the upper surface of the material. A downward force is applied to maintain the contact. Frictional heat, generated between the tool and the material, causes the plasticized material to get heated and softened & finally welding takes place through the joint line.

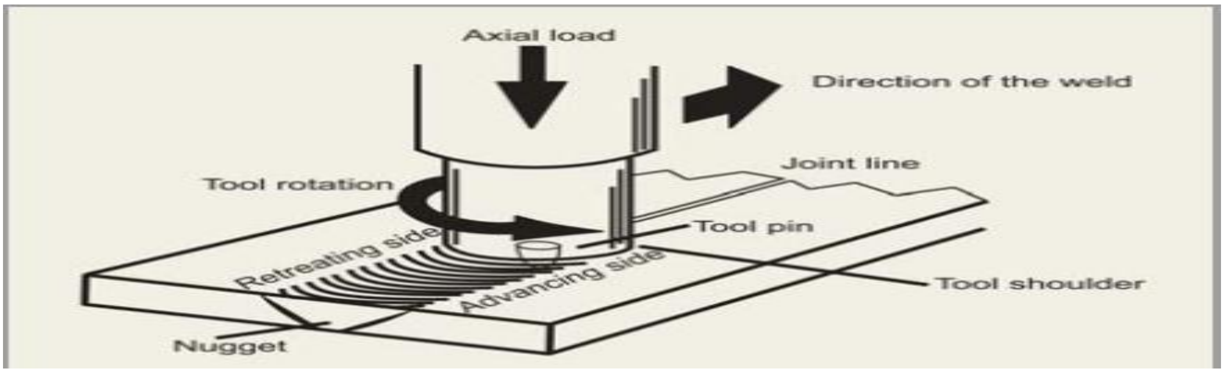


Fig. 1: Schematic of the friction stir welding process

III. Microstructure in FSW

According to Threadgill the four regions are (i) Parent Material, (ii) Nugget, (iii) Heat Affected Zone (HAZ) and (iv) Thermo-Mechanically Affected Zone (TMAZ).

i) The Parent material (or base material) is the region which does not undergo deformation and the microstructure in this region is not affected by the heat produced during the process.

ii) The Nugget region is formed by the intense plastic deformation induced mainly by the tool pin and consists of fine recrystallized grains.

iii) The heat affected zone (HAZ) is the region which is affected only by heat and there is no plastic deformation. In this region, the microstructure and/or properties are modified by the thermal heat.

iv) The thermo-mechanically affected zone (TMAZ) surrounds the nugget and it experiences lower temperatures and less deformation.

Friction stir welding is regarded as an Asymmetric process.

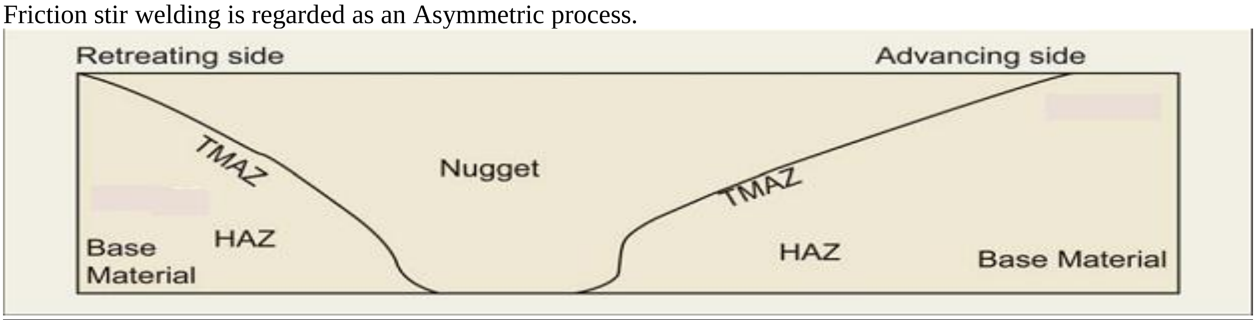


Fig. 2: Microstructure in FSW

IV. Effects of Process Parameters:-

1. Downward Force:- Frictional Heat, Maintain Contact b/w tool shoulder & workpiece.
2. Welding speed:- Appearance, Heat Control.
3. Rotational speed:- Mixing of material, breaking of oxide layer, some amount of frictional heat.

Applications of FSW:-

- Predominantly in the fabrication of aluminium components and panels.
- All transport industries including shipbuilding, automotive, rail and aerospace industries. In shipbuilding industry, for production of large aluminium panels.
- Large tanks for satellite launch vehicles.
- The railway industry uses FSW for the production of large prefabricated aluminium panels.
- The automotive industry uses FSW in the production of components like light alloy wheels and fuel tanks.

Advantages of FSW:-

- Fully automatic welding in all positions at high productivity and constant quality;
- Low thermal distortion.
- Limited weld seam preparation (no need to remove the oxide layer);
- No consumables, filler materials or shielding gases;
- No UV radiation, spatter, weld fume, high electric current, electromagnetic fields;
- High energetic efficiency;
- Limited maintenance and wear parts;
- Excellent repeatability.
- Low tool cost.
- Improved mechanical properties.

Disadvantages of FSW:-

➢ Welding of Spiral profile not impossible but difficult.
➢ High investment.
➢ Extensive clamping.
➢ Need backing support.

Objective of Our Work:-

Many researchers have worked to get various UTS under several control parameters. Our objective is to get optimum parameters to obtain maximum strength of the said Al-alloys.

Considerations for Experimental Procedures:-

❖ Input parameters or Independent Variables considered: -
  i) Rotational speed (N) in rpm,
  ii) Translation speed (v) in mm/min,
  iii) Axial Force (F) in KN,
❖ Tool Profile considered:-
  i) Cylindrical Pin.
❖ Al-Alloys considered: -
  i) AA-2024 $AlCu_4Mg$ (Heat-Treatable),
  ii) AA-5754 $AlMg_3$ (Non-Heat-Treatable)
❖ Output parameters considered: -
  i) Mechancal Properties- Tensile strength.
❖ Optimizing Methods considered: -
  i) Taguchi Method
  ii) Anova Method
❖ Software considered: -
  i) MINITAB

Composition of Al-Alloys:-

Al Alloy	Si %	Fe %	Cu %	Mn %	Mg %	Cr %	Zn %	Ti %	Specific Heat J/g ^{0}C	Thermal Conductivity W/m-K
AA-2024	0.5	0.5	3.8-4.9	0.3-0.9	1.2-1.8	0.1	0.25	0.15	0.875	121
AA-5754	0.4	0.4	0.1	0.5	2.6-3.6	0.3	0.2	0.15	0.897	132

Table: - 1

Specifications Considered For Experiment:-

- The height and diameter of cylindrical type tool pin was 2.8 mm and 6.0 mm, and thread screw of M6 was taken, respectively. The gauge section of tensile test specimens was located within the welded zone and had a size of 200 x 50 x 3 mm. Experiments conducted on vertical type-milling machine. [1]

[1] Observation & Calculation Table:-

Alloy	Experiment No.	Rotational speed (rpm)	Axial Force (KN)	Welding Speed (mm/min)	Tensile Strength (Mpa)			Avg. Ultimate Tensile Strength (Mpa)	Weld Performance
					Trial 1	Trial 2	Trial 3		Strength (%)
Base Metal								177.93	
AA-2024	A1	3000	25	15	137.15	135.3	131.82	134.76	75.74
	A2		22	10	141.23	141.2	136.9	139.78	78.56
	A3		20	7.5	109.95	117.16	114.25	113.79	63.95
	B1	2000	25	15	109.75	112.15	119.98	113.96	64.05
	B2		22	10	145.45	147.45	145.1	146.00	82.05
	B3		20	7.5	124.88	122.05	126.1	124.34	69.88
	C1	1000	25	15	120.35	124.1	122.15	122.20	68.68
	C2		22	10	132.8	131.92	126.78	130.50	73.34
	C3		20	7.5	114.15	117.22	120.2	117.19	65.86

Table: - 2

Alloy	Experiment No.	Rotational speed (rpm)	Axial Force (KN)	Welding Speed (mm/ min)	Tensile Strength (Mpa)			Avg. Ultimate Tensile Strength (Mpa)	Weld Performance
					Trial 1	Trial 2	Trial 3		Strength (%)
Base Metal								235.17	
AA-5754	A1	3000	25	25	121.25	122.1	121.53	121.63	51.72
	A2		22	20	108.08	179.91	109.2	132.40	46.09
	A3		20	15	100.35	101.02	101.85	101.07	42.98
	B1	2000	25	25	93.5	95.75	98.95	96.07	40.85
	B2		22	20	102.35	100.89	98.95	100.73	42.83
	B3		20	15	110.15	107.32	105.95	107.81	45.84
	C1	1000	25	25	103.18	105.19	107.05	105.14	44.71
	C2		22	20	107.5	106.85	105.25	106.53	45.3
	C3		20	15	108.95	109.25	107.19	108.46	46.12

Table: - 3

Experimental layout of L_9 Orthogonal array

S.I No	Experiment's notation	Friction Stir Welding Parameters level		
		A Rotating speed in rpm	B Axial Force in KN	C Travel speed in mm/min
1	A1	**1**	**1**	**1**
2	A2	**1**	**2**	**2**
3	A3	**1**	**3**	**3**
4	B1	**2**	**1**	**2**
5	B2	**2**	**2**	**3**
6	B3	**2**	**3**	**1**
7	C1	**3**	**1**	**3**
8	C2	**3**	**2**	**1**
9	C3	**3**	**3**	**2**

Table: - 4

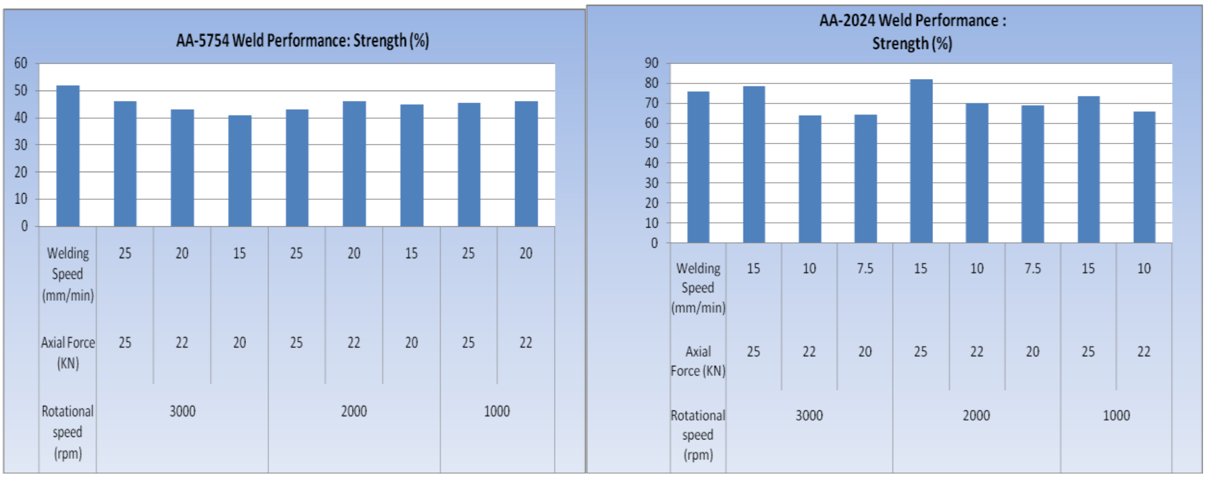


Chart: - 1

Analytical Analysis of AA-5754 by Taguchi Method:-

V. Results and Conclusion:-

The Rotational speed ranks first in the contribution of good joint strength, while Travel speed and Axial Force take the second and third ranks respectively.

The tensile strength is estimated to be the maximum with the best combination ie at 3000 rpm rotation speed, 22 KN Axial force and 25 mm/min travel feed.

Results obtained Using MINITAB:-

Taguchi Design for AA-5754

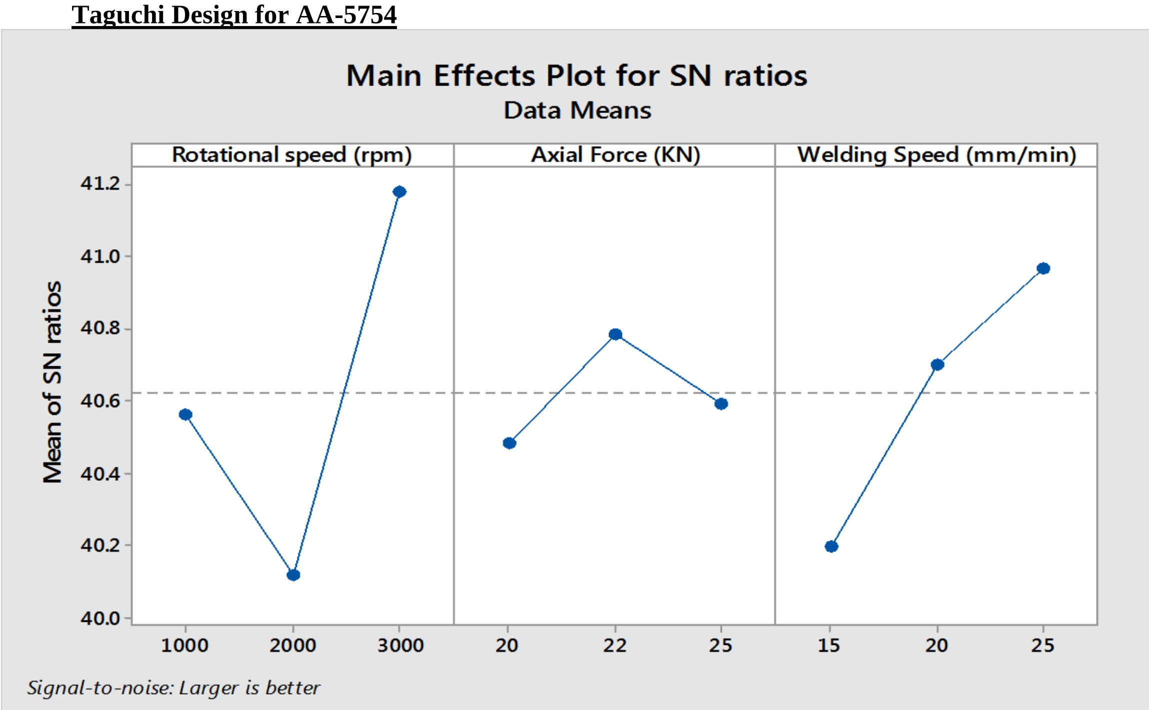


Chart: - 2

Predictions from Taguchi Analysis for AA-5754:-

The Optimum combination of parameters obtained from the main effect plot for the S/N ratio and mean with the best combination at 3000 rpm Rotational Speed, 22 KN Axial Force and 25 mm/min Welding Speed and the Optimized Tensile Strength has been predicted as 163 MPa.

Results obtained Using MINITAB:-
ANOVA for AA-5754

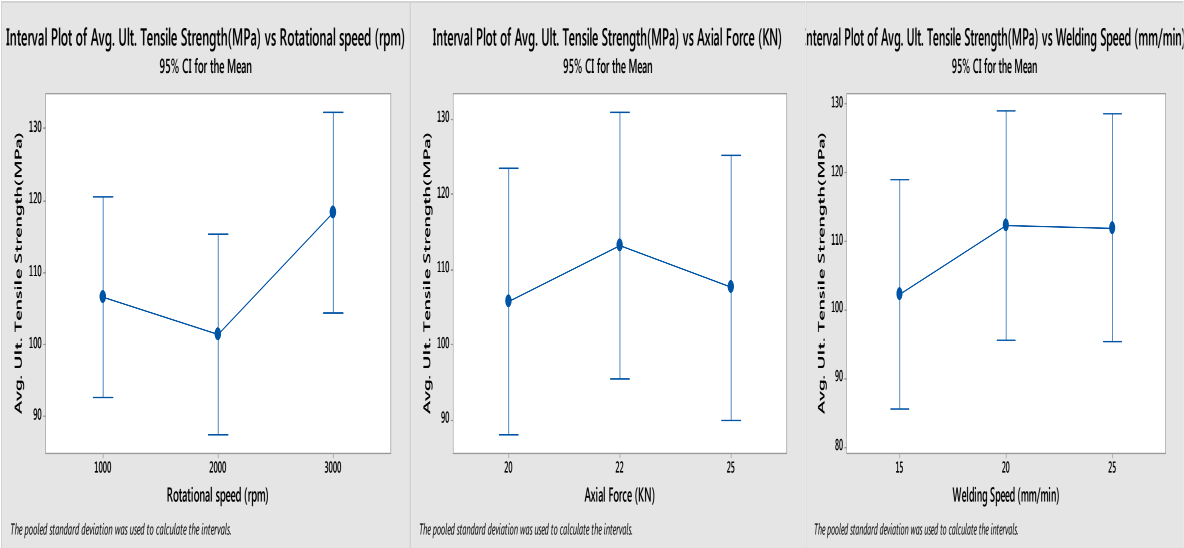
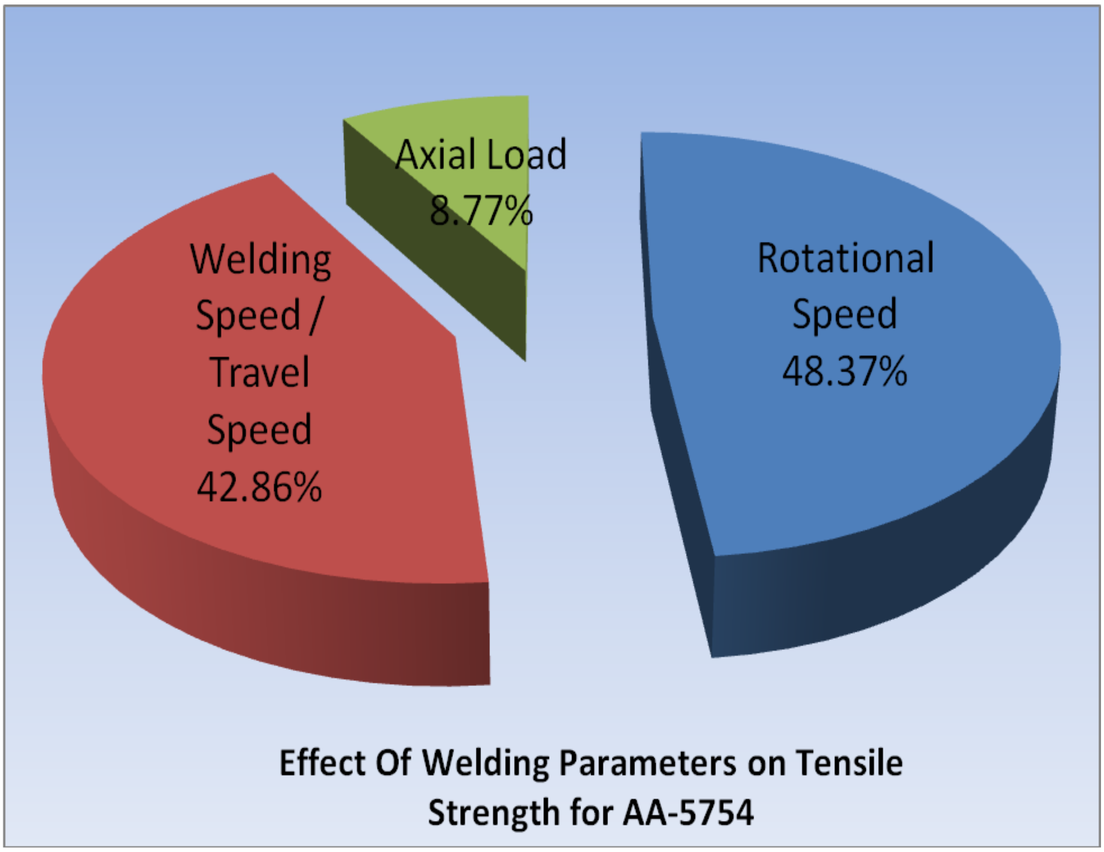


Chart: - 3



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Results obtained Using MINITAB:-
Taguchi Design for AA-2024

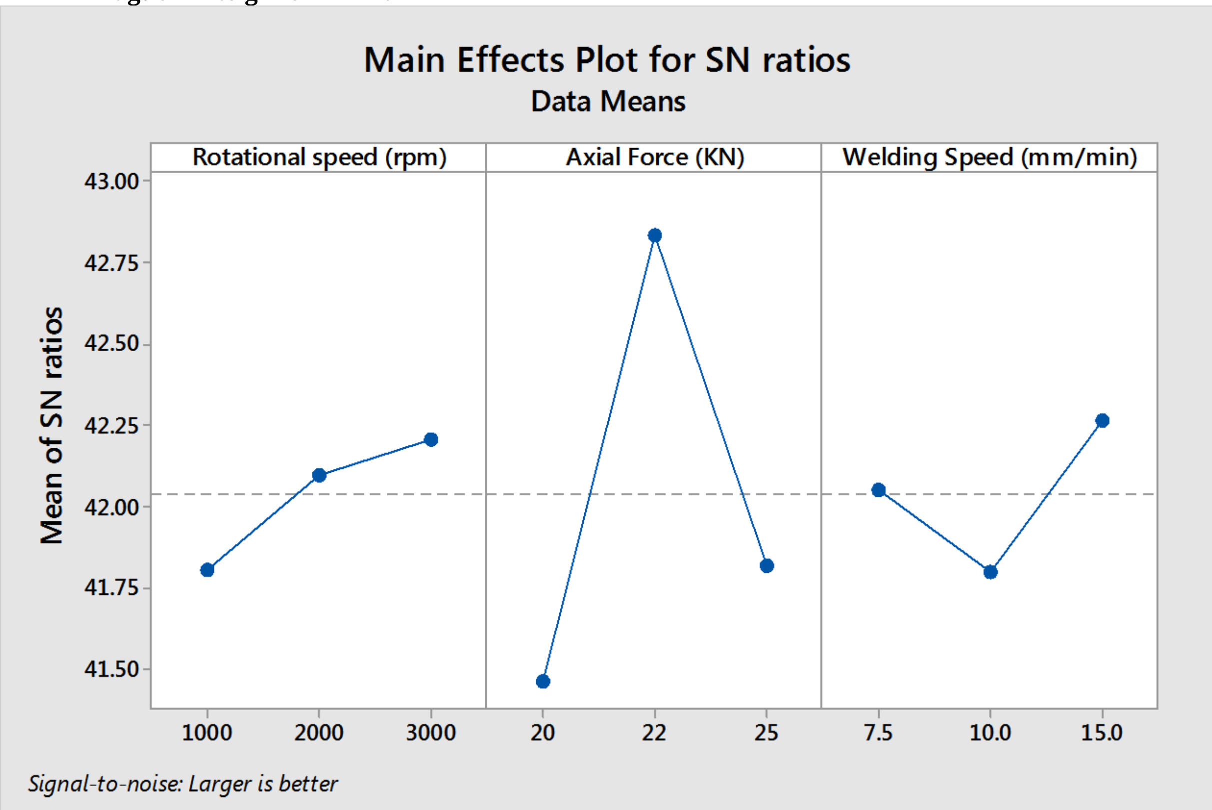
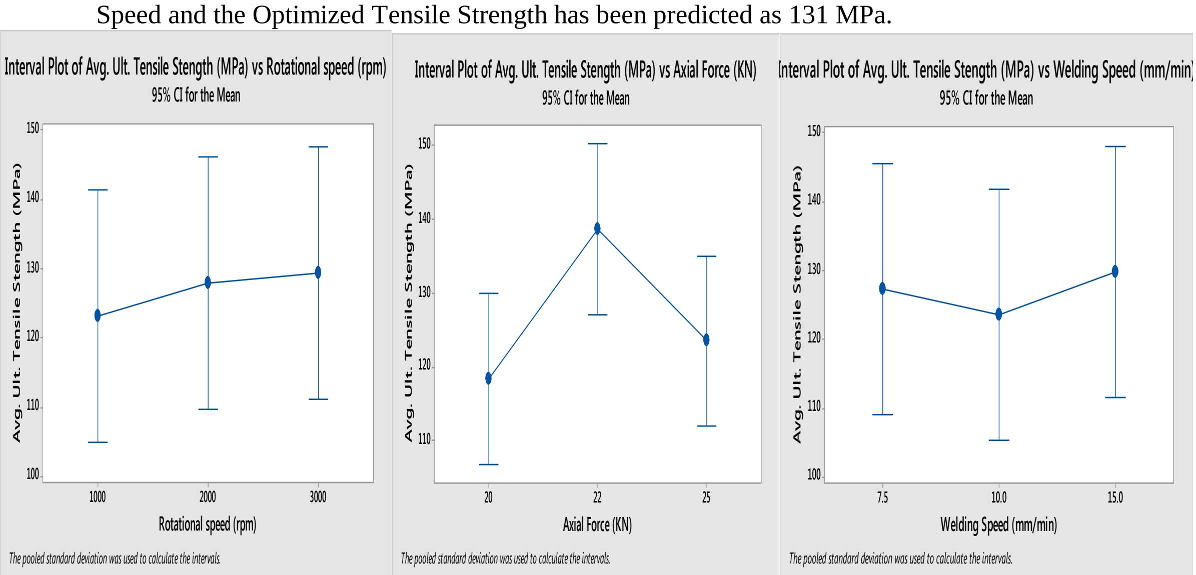


Chart: - 5

Predictions from Taguchi Analysis for AA-2024:-

The Optimum combination of parameters obtained from the main effect plot for the S/N ratio and mean with the best combination at 3000 rpm Rotational Speed, 22 KN Axial Force and 15 mm/min Welding Speed and the Optimized Tensile Strength has been predicted as 131 MPa.



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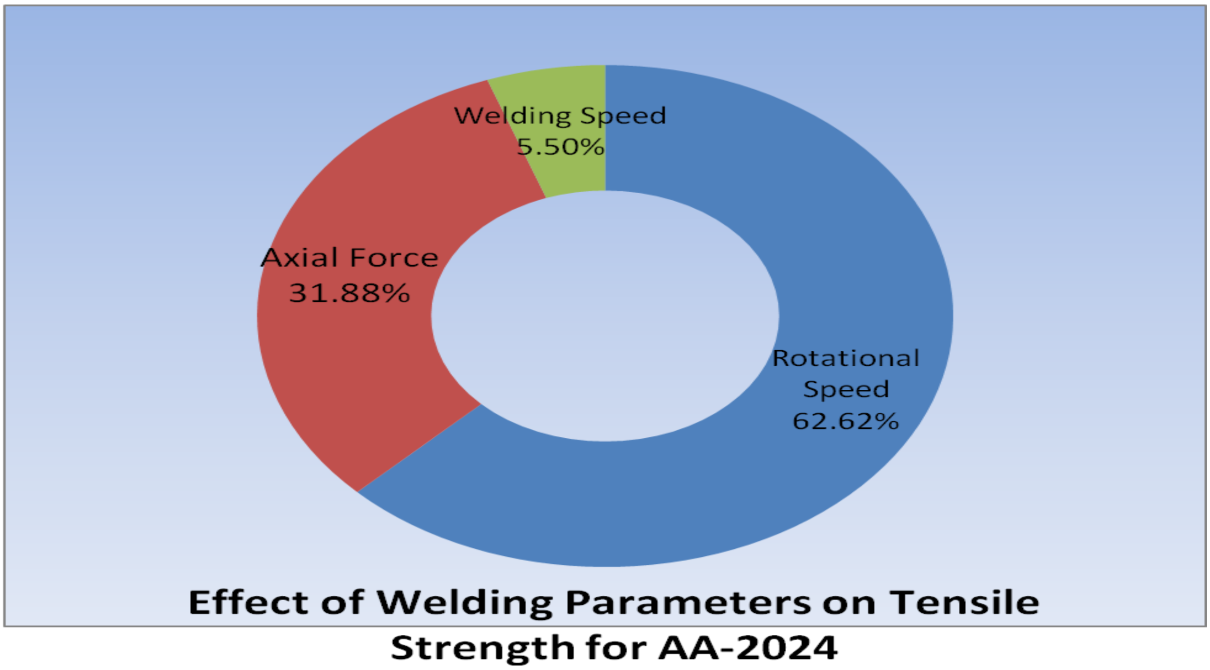

Chart: - 7

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