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Some Experimental Investigations in Friction Welding of Dissimilar Alloys

Zakir Maqbool Bhat[1], Dr Sachin Saini [2], and Er. Deepak Kumar[3]

[1] Research Scholar, RIMT University, Mandi Gobindgarh, Punjab, India
[2,3]Assistant Professor, University, Mandi, Gobindgarh, Punjab, India

ABSTRACT- Friction welding offers a number of benefits over conventional techniques by using the force of friction to successfully fuse metals. The study's main objective is to identify regions with unrealized potential and investigate current trends in friction welding. These advantages include improved tensile strength, refined grain hardness, and superior metallurgical characteristics compared to the original metal. The specific goal of the research is to provide light on areas that have not yet reached their maximum potential. This study collects and examines friction welding anecdotes with an emphasis on welding settings, testing procedures, and the materials used in the welding process. By examining these important areas in detail, the study delves into the subtleties of friction welding. It is clear that rotational speed is an important and crucial factor. Heat input and stress analysis using sophisticated techniques, however, are still neglected. This assessment suggests recommendations for the manufacturing sector, emphasizing potential benefits for industrial applications in the future. The results highlight the necessity of doing additional research and applying heat input and stress analysis to friction welding procedures in order to improve manufacturing efficiency and results. In this work, an attempt has been made to weld the stainless steel SS202 and aluminium alloy AA6063 using the method of friction welding under the various welding parameters, yielding a sound welded connection with an 83% joint efficiency.

KEYWORDS- Friction welding, Dissimilar joint, AA6063, weld efficiency, SS202, Micro-Hardness.

I. INTRODUCTION

Friction welding, which is a variant of pressure welding, forms welded connections without melting the base metal. It achieves joint plastic deformation by generating localized intense heat through friction [1]. This process minimizes energy consumption and also produces a great amount of heat, robust welds due to substantial heat and deformation and a strong weld is formed [2]. As we know the friction welding is a process of solid state welding, it doesn't form the pool of molten metal with the result eliminates the errors due to solidification. Friction welding seamlessly joins diverse materials with distinct properties like thermal and mechanical properties but at the same time maintaining the strength of weld joint. Its advantages, including cost-effectiveness, repeatability, precision, and reliability, make it a superior choice over conventional methods [3].For the duration of welding among the two parts one part which is rotating at very high speed and the other is fixed. In order to bring the two parts close to each other axial force is given to the fixed part [4, 5.]. The tubular and solid sections can also be welded together by friction welding. When the axial force is applied and also due to high heat of friction a flash at interface of the two parts is generated.

The ability to friction weld virtually any forgeable metal gives engineers the opportunity to construct bimetallic structures, utilizing a variety of bimetallic friction joints for a wide range of technical applications. A few examples of popular bimetallic frictional connections like Al-Cu joint, Al-steel joint, Cu-Ti joint etc.

Although friction welding eliminates the need for heat input or flux, it can nevertheless be used to link aluminum and copper, despite the fact that this is typically thought of as an unwelded joint[6, 7]. Additionally, there are fewer faults in friction welding than in fusion welding, and friction welding is the fastest method in terms of speed when compared to fusion welding. Furthermore, friction welding is thought to be twice as fast—or possibly 100 times faster—than traditional fusion welding. The goal of the current research is to determine various process factors on various substrate materials throughout the welding process by conducting a literature review on friction welding.

Paventhan et al. [8] the study aimed to establish a predictive relationship for the tensile strength of friction-welded AISI 304 austenitic stainless steel and AISI 1040 medium carbon steel. Key process parameters,— friction time, friction pressure, forging pressure, and forging time — which were considered for their significant impact on joint strength. Employing response surface methodology, the researchers systematically optimized these friction welding parameters to achieve the peak possible tensile strength in the subsequent joint. This approach enhances our understanding of the interplay between process variables and tensile strength, underwriting to the effective utilization of friction welding in joining dissimilar material's with varying mechanical properties.

Joints exhibit an extreme tensile strength of 543 MPa, under specific welding conditions. This was attained with a forging pressure and friction pressure of 90 MPa each, coupled with a friction time and forging time of six seconds each.

Winizenko and Kaczorowski, [9] The researchers examined the microstructure and mechanical properties of a friction-welded arrangement of ductile iron and stainless steel,. They utilized scanning electron microscopy (S.E.M) to scrutinize observe phase transformations and fracture morphology occurring in the friction welding process. During friction welding, the transportation of atoms is directionally across the interface between stainless steel and ductile iron. This process leads to the enhancement of iron with chromium and nickel and stainless steel with carbon atoms.

The improvement of carbon in stainless steel leads to the development of chromium carbides, primarily distributed along grain boundaries. . Chromium is also present in a carbide eutectic. Enrichment of iron with chromium and nickel results in the formation of an alloy ferrite. Generally, the diffusion range of nickel and chromium in iron does not exceed fifty meters. . The diffusion processes' intensity is notably greater in the friction welding of bainitic ductile iron compared to ferritic ductile iron. In instances where a joint undergoes a double thermal effect, the depth of carbon diffusion reaches 150 meters, surpassing that of a sample subjected to single-step friction welding.

Selvamani and Palanikumar [10] this study focuses on optimizing the process parameters for friction welding 12mm diameter AISI 1035 graded steel rod. The joints undergo various process parameter groupings, using ANOVA methods, and are subjected to a tensile test and the research successfully achieves a extreme tensile strength of 548.44 MPa in the friction-welded AISI 1035 grade medium carbon steel rods. This optimal result is obtained under specific welding conditions, including a friction pressure/time of 28.8 MPa/s, a forging pressure/time of 29.40 MPa/s, and a rotational speed of 24.410 (RPS). Rotational speed was found to have greater influence on tensile strength of the joints followed by Friction pressure and Forging pressure.

Prasanthi et al. [11] this study focuses on establishing a flawless bonded interface between mild steel (MS) and titanium (Ti) through the rotational friction welding process. The investigation systematically optimizes conditions through multiple trials, manipulating key friction welding parameters such as frictional force, upset force, burn-off length, and rotational speed. Successful fabrication of friction welds between mild steel and grade-2 titanium is achieved by employing optimized values for these parameters, namely 0.8 tonnes for frictional force, 1.6 tonnes for upset force, 3 mm for burn-off length, and 1000 rpm for rotational speed.

Kimura et al [12] the study investigated the joining phenomena and tensile strength of a friction-welded joint between titanium alloy (Ti–6Al–4V) and low carbon steel (LCS). Various aspects of the joining process, including joining behaviour, friction torque, and temperature changes at the weld interface, were meticulously measured. Furthermore, the impact of friction pressure, friction time, and forge pressure on joint strength was thoroughly examined. The metallurgical characteristics of the joints were observed and analysed, providing valuable insights into the intricacies of the friction welding process for these specific materials.

Reddy [13] the study aimed to evaluate the friction welding process of AA1100 and Zr705 alloy using finite element analysis. Key process parameters, including frictional time, frictional pressure, rotational speed, and forging pressure, were analysed. The joints underwent assessment for strength, bulk deformation, penetration, and flange formation. In the context of friction welding AA1100 and Zr705 alloy, it was determined that the forging pressure should be 1.25 times the frictional pressure. The study identified optimal operating conditions for satisfactory friction welding of AA1100 and Zr705 alloy, specifying a frictional pressure of 25 MPa, frictional time of four seconds, rotational speed of 2000 rpm, and forging pressure of 31.25 MPa.

McAndrew et al. [14] make the research on friction welding of titanium (Ti-6Al-4v) which is used for manufacturing of bladed disks, in aero engines. This finding shed light on the crucial aspects of linear friction welding and the limitations of it.

Sachin saini et al. [17] the purpose of this study was to examine sound welded surfaces, which may be distinguished from inferior welds by using microstructures and micrographs.

II. EXPERIMENTATION

A. Problem Formulation

It appears from the research that is currently available that there is a lack of understanding regarding process variable optimization for friction welding of cylindrical materials, like SS202 and AA6063. It is extensively utilized in numerous industries. It does not seem that any present efforts are addressing this crucial aspect of enhancing the friction welding processes for these materials (AA6063 & SS202). So from the available literature review a gap has been found for the welding of the ferrous and non-ferrous alloy [19-20] using the method of the friction welding so that an attempt has been made from that array these two alloys were found i.e. AA6063 & SS202.

B. Research Objectives

Finding and evaluating the tensile strength, impact test and micro hardness of the AA6063 and SS202 joint by using FW.

C. Material

The materials chosen for this work are aluminum 6063 alloy, SS202 low alloy steel as these are widely used in industrial and domestic applications. The chemical composition of AA6063, SS202 is listed in table 1 and table 2.

Table 1: Chemical composition (wt. %).

Material	Al	Zn	Mn	Be	Cu	Fe	Si	Ti	Mg	Cr
AA 6063	98.57	0.061	0.045	-	0.029	0.26	0.50	0.02	0.04	0.01

Table 2: Chemical composition (wt. %)

Material	C	P	Mn	Be	S	Fe	Si	Ni	Mg	Cr
SS 202	0.15	0.06	9.25	-	0.03	68	0.51	4.1	-	17.1

Table 3: Material properties

Name of material	Ultimate Tensile Strength, Mpa	Elongation ,%	Impact Strength, Mpa	Hardness, Hv
AA6063	215	10	68.9	83
SS202	515	40	-	203

The chemical compositions and qualities of the materials are listed in Table 1, table 2 and table 3 respectively. Varied alloys have varied properties because of their differences in composition. SS202 offers exceptional corrosion resistance in the automotive, aerospace, home, and power plant industries. In AA6063, Silicon accounts for only 0.51% with magnesium (0.40%) and iron element (0.26%) following closely behind. Due to its lightweight nature, good machinability, heat treatability, and weld ability, it is widely used in applications such as architectural fabrication, window and door frames, cycle frames, furniture, pipe, and tubing [17].

D. Analysis and Testing

After welding, tensile, bending, and hardness tests were utilized to evaluate the mechanical properties of each weld, and other mechanical and metallurgical tests were conducted on each specimen. According to ASTM standards, tensile and impact specimens were cut perpendicular to the weld direction using a lathe and a mechanical circular saw machine, respectively (Figure. 1). A computer-controlled universal testing machine (ASTM E8M-04) and an impact test machine were used to conduct the tests, and both had a 1% accuracy level in accordance with Associated Scientific Engineering Works.

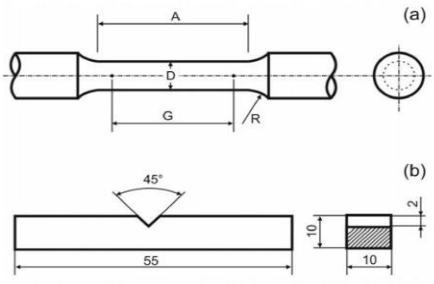

Figure 1: Tensile test specimen dimensions (in mm), d-9, a-54, r-8, g-45,. (b) v-notch impact test specimen [as per astm e8m-04 standard]

E. Tensile Test

The tensile testing for the specimen as per ASTM E8 standards which is carried out with dimentions of 8mm gauge diameter, 10mm gauge diameter, 12mm gauge diameter and length of 300mm each for AA6063-SS202 welded work-pieces, in a universal testing machine. The specimen were tested and the values are noted, from the results it was found that the tensile strength increases but only up to certain limit and then decreases. Better penetration and increased heat generation between the two weld surfaces are the outcomes of the increase in rotational speed.

The experimental findings serve as an input function for Taguchi's analysis, which is performed using a commercially available statistical tool to examine the data for the AA6063-SS202 dissimilar welded joints. The influence of process parameters like rotational speed, weld time, and diameter on tensile strength of AA6063-SS202 dissimilar welding joints was analyzed using signal to noise (S/N) ratio. The results were transferred into the signal to noise ratio (S/N) for the determination of quality attributes.

Capacity – 15 KN
Maximum crosshead travel – 1200mm
Testing speed range – 0.001 to 1000 mm/min
Mximum crosshead speed at 5KN – 550mm/min

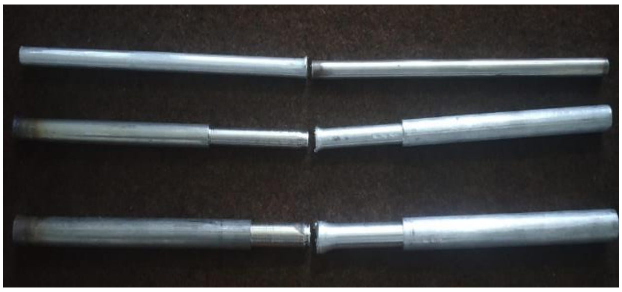

Figure 2: Tensile specimen (following a tensile test)

F. Impact Test

The Impact Charpy test was conducted at room temperature using a pendulum-style impact testing apparatus. The impact toughness of the material is determined by measuring the energy absorbed in the fracture; the work specimens were positioned at the centre line with the weld joint. Because the material was appropriately blended to produce joints. The toughness or impact strength of dissimilar joints AA6063-SS202 by friction welding was observed at room temperature and the final results are obtained. The energy absorbed in the cross-sectional area by the welded joint is calculated by impact strength. In general charpy impact is used to determine how rapidly the crack will propagate once it was started and how easily it would start/initiate in the specimen. From the final results the maximum of 48 joule energy was recorded for the specimen of 12mm diameter and the fracture was found at the welded region, at which the material breaks into two pieces. The values obtained during the impact test are shown in the table 4 and specifications of impact testing machine are as follows,

Initial potential energy (joules)	300
Pendulum drop angle	145
Angle of striking edge	35
Radius of striking edge	9mm
Distance between anvils	50mm
Width of tip	5mm

Table 4: values obtained during Impact test (in joules)

Diameter(mm)	12	10	8
Impact Strength (Joule)	48	8	4

III. MICRO HARDNESS

Vickers micro-hardness across the welded zones, from the weld interface to the base metals, was assessed using the Vickers hardness tester. The specimens were polished and the diamond-shaped pyramid was used to create the surface deformation. Calculations of hardness were made based on the loads placed on the specimen [21]. For 10 seconds, a load of 200 grams, or 0.20 kg. was applied in the hardness test. The eyepiece's scale was utilized to record the dimensions of the diamond impressions. In addition, the values from the AA6063 side are recorded as 38, 46, and 54 at the weld zone, HAZ, and base metal, respectively. The values from the SS202 side are specified as 291, 283 and 253 at the weld zone, HAZ, and base metal, respectively. So from the results recorded it can be easily predicted that the hardness of SS202 from the weld zone towards the base metal decreases and that of AA6063 the hardness increases from weld zone towards the base metal. The soft nature formed at the weld interface results in lower hardness as compared to the other regions.

IV. RESULTS AND DISCUSSION

A. Taguchi Technique

This experiment makes use of the Taguchi approach, which was developed by Genichi Taguchi in 1980 [22]. The ability to plan ahead and see future research goals and equipment requirements is a critical function of work planning. Gineche Taguchi developed these mathematical methods, often known as rigorous design approaches, to reduce production costs. More recently, they have been used to engineering, biotechnology, marketing, and advertising. This method is used to formulate all statics data; expert statisticians praised Taguchi's objectives and advancements, particularly the introduction of Taguchi designs to evaluate variance, but criticized some of his suggestions as needlessly complicated. This is a simple yet efficient method for maximizing performance attributes within the constraints of a given set of process variables.

Table 5: Welding parameters for Optimization.

Welding parameters	L1	L2	L3
a – Speed, (rpm)	692rpm	832rpm	1228rpm
b– Weld time, (sec)	22 sec	32 sec	41 sec
c – Dia. (mm)	12.00 mm	10.00 mm	8.00mm

B. Signal to noise ratio

The terms signal (S) and noise (N) indicate the desired and undesired effects on the output characteristic. The experimental findings serve as an input function for Taguchi's analysis, which is performed using a commercially available statistical tool to examine the data for the AA6063-SS202 dissimilar welded joints. The influence of process parameters like rotational speed, weld time, and diameter on tensile strength of AA6063-SS202 dissimilar welding joints was analysed using signal to noise (S/N) ratio Figure 3. The results were transferred into the signal to noise ratio (S/N) for the determination of quality attributes.

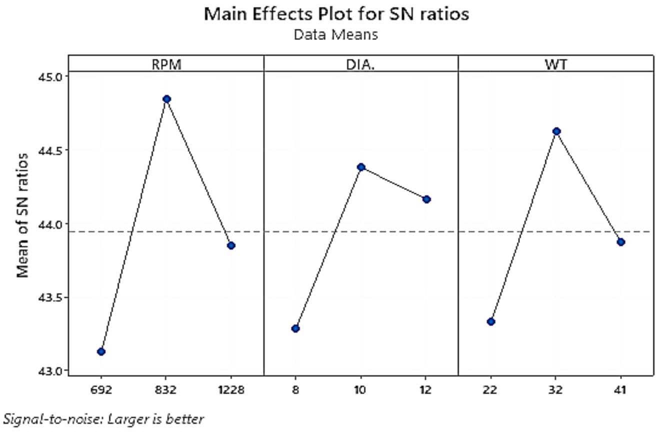

Figure 3: Signal to noise ratio

C. Testing Results

The work specimens had irregular and rough surfaces, when they were first trail welded on a manual lathe machine at 492 rpm with manual axial pressure. Figure 4 below shows trail welding setup-

Figure 4: Setup for trail welding

Subsequently, the parameters were adjusted [23], producing sound welds with few faults. Tensile tests were performed on the specimens after they had been welded using a Lathe machine at varying RPM and WT. Figure 5 below shows Lathe machine and welded joints –

Figure 5: Lathe machine welded joints

The results obtained from tensile test had been recorded in the given table 6 below-

Table 6: Results obtained from tensile test

Sr no.	Speed(rpm)	Weld Time (sec)	Tensile Strength (MPa)
1	692	22	158
2	692	22	165
3	692	22	150
4	832	32	180
5	832	32	175
6	832	32	169
7	1228	41	145
8	1228	41	157
9	1228	41	166

The given graph (Figure 6) shows the tensile strength variation with respect to speed and WT.

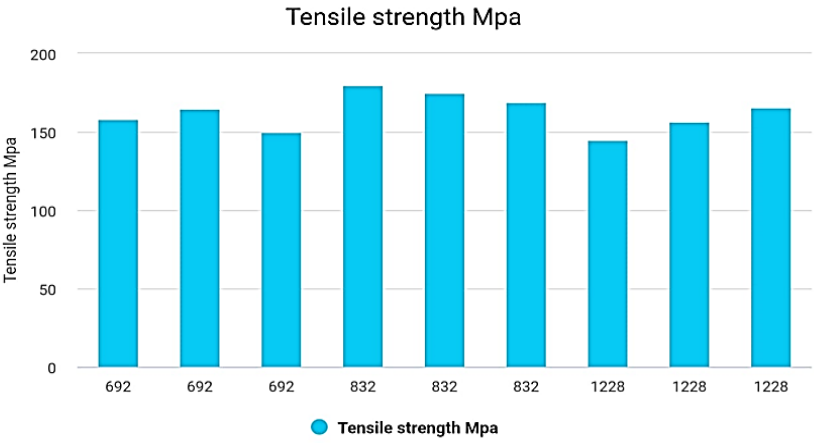

Figure 6: variation of tensile strength

Following each specimen's impact test, the impact energy values were noted from the machine scale. The impact strength values were then computed using the cross-section area value. The impact test findings had been documented in the given table 7 below-

Table 7: Impact test findings

Sr.no	Speed(rpm)	WT(sec)	Dia. (mm)	Impact energy (joule)
1	692	22	12	48
2	692	22	12	47.3
3	692	22	12	47
4	832	32	10	8
5	832	32	10	7.5
6	832	32	10	7.2
7	1228	41	8	4
8	1228	41	8	4.2
9	1228	41	8	4.4

The given graph (Figure 7) shows the Impact energy variation with respect to speed, WT and Dia.

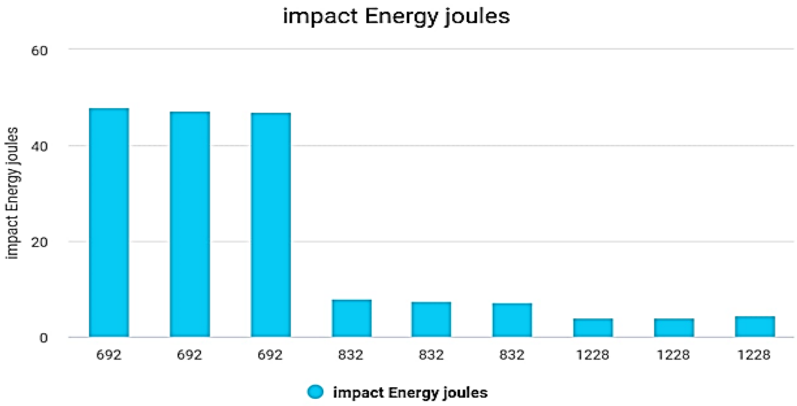

Figure 7: Variation of Impact energy

Testing equipment was used to evaluate each weld's tensile strength [19] after the testing specimens were prepared in accordance with the standard. During the test, the majority of the fracture occurred near the weld joint. Tensile testing yielded results such as yield and tensile strength and an axial shortening relation with weld strength. Among the trials, the weld joint's highest tensile strength was approximately 180 MPa at FT 32s, meaning that the FT altered the joint's tensile properties. Simultaneously, the 41s FT welding method resulted in elevated frictional heat at high pressure, over-softening the AA6063 soft material, and ultimately lowering the weld strength. Tensile and yield strength decreases with increasing axial shortening and remain almost constant when the axial shortening is between 27 and 30 mm. A maximum of 83% joint efficiency was achieved for 32s FT. It can be raised even more by adjusting the different settings and surface adjustments. When the joints were tensed, the peak load was nearly equal to 13 KN, and the test revealed less than 9% elongation. Therefore, variations in FT can alter the qualities of the weld joints; even small variations can result in noticeable changes to the joints' characteristics.

Because of the calibration that was done, the hardness tester provides direct values of the micro hardness. The hardness variation on both sides of the weld zone was computed, and a graph was displayed.

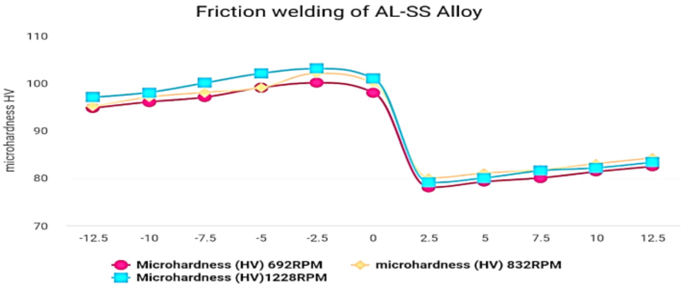

Figure 8: Micro hardness plot for various rpm’s

Figure 8 displays the micro hardness distributions perpendicular to the weld interface of joints. All of the micro hardness curves exhibit a distinct V-shaped region at the Al alloy side, indicating the occurrence of a softened region close to the weld interface. The relatively large amount of β precipitates in the weld zone usually results to the lowering of micro hardness [17]. Due to increased friction heat, which encourages the overaging phenomenon of Al alloy, a broader softened zone is produced during extended friction times. Along similar lines to the diffusion zone, the softened area's thickness increases within the range of welding conditions when friction duration is prolonged and upset pressure is low. Despite this, the steel side's high strength almost completely preserves its micro-hardness.

V. CONCLUSIONS

Following are the conclusion points on friction welding between AA6063 and SS202 dissimilar metallic welded joints.

- The setup made for the friction welding has successfully welded the ferrous and non-ferrous alloys and also proves that the friction welding is an efficient method to join the two alloys. It has better properties and better bonding than other joining methods.
- The rotary friction welding between dissimilar joints, such as AA6063 and SS202, was successfully completed by employing varied parameters. The tensile strength is primarily affected by rotating speed. The maximum tensile strength obtained was approximately 180 Mpa at the WT of 32 seconds.
- According to the final results, the specimen with a diameter of 12 mm had a maximum of 48 joule energy, and the fracture was discovered at the welded region. In SS202, hardness declines from the weld zone to base metal, while in AA6063, it increases. The soft weld interface contributes to lesser hardness relative to other regions.

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