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Parametric Analysis and Investigation of Rotary Friction Welding based on Comparative Study between SS304 and SS316

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***Abstract:** In today's economical challenging world, metal industries are facing problems such as high cost and time, lack of strength. Rotary friction welding provides satisfactory results to overcome these problems. Rotary friction welding is done by convection mechanism. Due to increased sophistication of metals and their composition, it has become essential for various industries to have precise understanding of all material properties and how they can be welded in the most efficient way. In this research paper, ss304 and SS316 ARE taken into consideration for parametric analysis and comparison due to their high utilization rate in various industries. The research paper considers the analysis of Temperature, Pressure, Time for weld, Heat affected zone in rotary friction welding technology. It considers the strength of the weld (breaking, ultimate, yield strengths).*

***Keywords:** Friction welding, Stainless Steel 304, Stainless steel 316, Rotary friction welding, heat affected zone.*

I. INTRODUCTION

Many automobile and aerospace manufacturing industries are using rotary friction welding in order to join round parts like valves, transmission rods, shanks and bimetallic valves. In this type of solid state welding process, one part is rotated against another by applying compressive type of axial force. Due to friction between two parts heat is generated which causes the surface material to melt. This deformed state of part due to compressive force gets diffused with another part which forms a permanent welded joint by displacing the oxide layer and other contaminants produced during the process. This research paper aims at analysing various parameters such as temperature, pressure, time and heat affected zone for rotary friction welding of SS304 and SS316. This analysis is carried out by considering breaking strength, ultimate strength and yield strength of welded joints.

There are many advantages offered by rotary friction welding over other welding techniques commonly used in manufacturing industry. As this welding process can be easily repeated and can be carried out without human intervention, this process can be easily automated which results in high process efficiency. RFW being a solid state welding process the defects such as pores or cracks formed due to solidification are avoided which essentially used to occur due to melting of parts. This welding process also has lower peak temperatures than other welding processes which makes it possible to weld dissimilar metals as well. No additional requirements such as filler material or shielding gas are required for this welding technique. Hence the manufacturing cost is comparatively low for rotary friction welding. Due to so many advantages, RFW is extensively used to manufacture piston rods, turbine shafts, cutting tools, axles and steering rods etc.

There are three different regions in rotary friction welds which are as follows-

1) Heat affected zone (HAZ)
2) Weld Centre Zone (WCZ)
3) Thermo-mechanically affected zone (TMAZ)

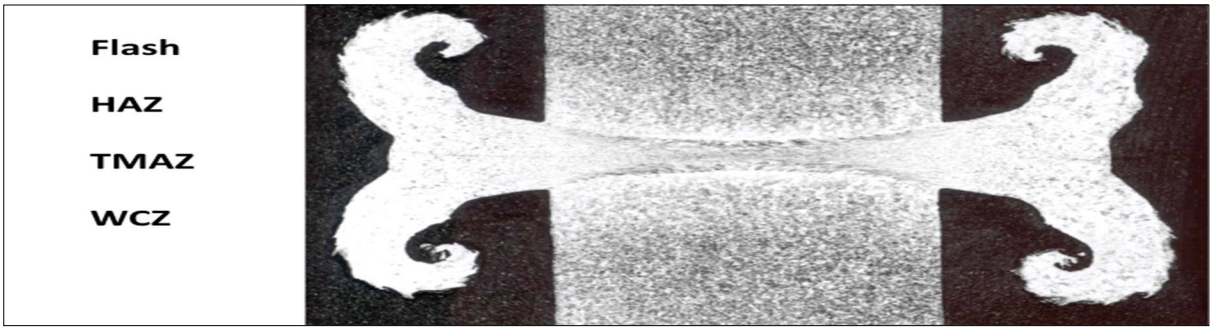


Fig.No 1 Section of Rotary friction weld under microscope

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There are two types of rotary friction welding based on how energy is delivered to weld surface which are as follows-

a) *Direct Drive Friction Welding:* The rotating motor spindle continuously drives the workpiece to be welded over the stationary workpiece in order to form welded join in between the interface. This is method is also called as continuous drive friction welding. In this process clutch is used in between motor and spindle in order to disconnect spindle from drive once the required parameters are achieved. For emergency purposes brakes are used to sop the spindle from rotating.

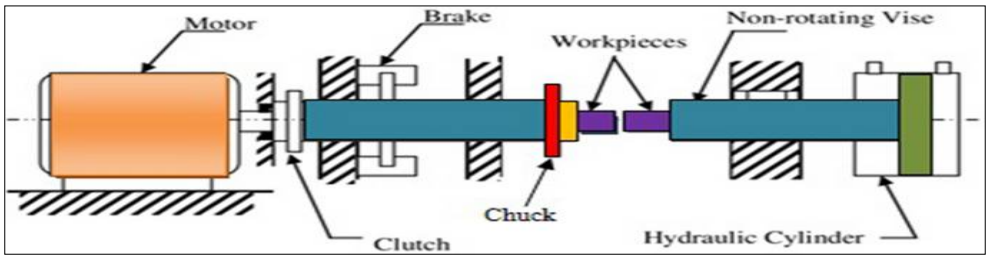


Fig.No 2 Schematic representation of direct drive friction welding

b) *Inertia Friction Welding:* In this technique drive motor is used to supply power to the flywheel. One workpiece is held along with flywheel while other is held stationary in non-rotating vise. Workpiece is rotated to a high speed along with flywheel. Once the required speed is attained flywheel is disconnected. Kinetic energy present in flywheel gradually reduces due to friction and it is dissipated in environment in the form of heat generated at the weld interface. This rise in temperature contributes to form welded joint when pressure is applied from both end. This pressure is kept constant in order to allow weld to set.

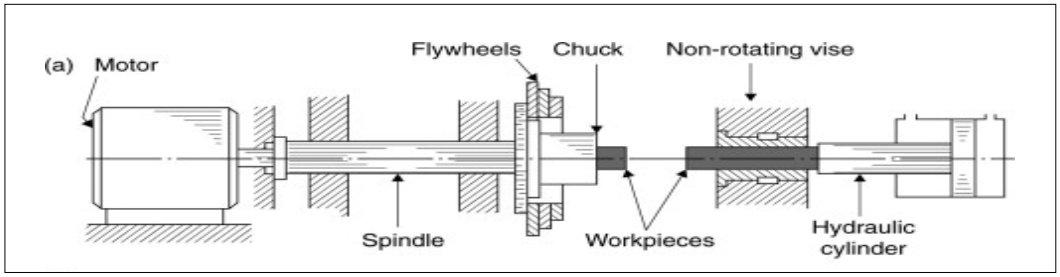


Fig.No 3 Schematic representation of inertia friction welding

These types of welding processes are used to join wide range of geometries which includes connecting tube to bar, plate, disk and to tube itself. It is also used to connect bar to bar and bar to plate. Along with this rotating ring is also used to connect long components.

A. Stages in Rotary Friction Welding

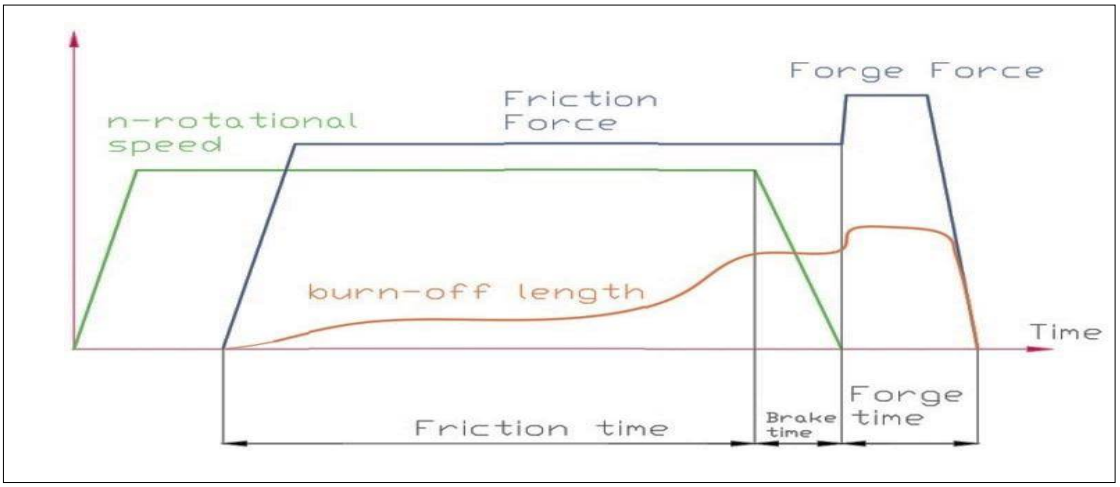


Fig.No 4 Stages in rotary friction welding

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Before starting the process surface of two parts to be welded are cleaned and prepared. Once the parts are ready, one part is held in stationary jaw and other part is attached to rotating spindle. Then part is rotated until required speed is achieved and held constant at that speed. After this hydraulic cylinders apply frictional force on the rotating component. Friction force is held at certain pressure till the determined friction time. Due to constant frictional force between two parts there is a rise in temperature at interface. In the braking stage workpiece in rotary motion is brought to standstill position. After completion of braking stage forging pressure is applied to the component being welded to form welded joints. Usually flash is produced after the forging stage which can be removed later by welder.

However in the stages in rotary friction welding-

1) There can be modifications present in the process of welding
2) Variety of welding machines can be used to perform the operation.
3) Many materials differ in their properties and shapes hence process parameters mentioned above also differ
4) Actual curve parameters might differ from the theoretical curve mentioned above.

II. PROBLEM STATEMENT

To conduct experiment to join samples of SS304 and SS316 same and different cross section using rotary friction welding and perform tests for strength of welded samples using tensile test and perform parametric analysis of heat affected zone.

Parameters considered during welding-
1. Force 2.Time 3.Speed 4 Temperature

III. EXPERIMENTATION SETUP

1) Perform RFW on samples of SS304 and SS316 of same and different cross section.
2) Tensile Test.
3) Hardness test at different locations of HAZ.
4) Microstructure analysis of welded joints
5) Hardness test of welded joints
6) Analytical Work

Experimental work of Research work and for finding new possibilities of friction welding using Specimen 1, 2, and 3 resp. dia. = 10 mm, dia. = 12 mm, dia. = 14 mm (Stainless Steel of grade 304 and 316)

Table 1: Chemical composition comparison of SS304 and SS316

	Type 304	Type 316
Carbon	0.08% max.	0.08% max.
Manganese	2.00% max.	2.00% max.
Phosphorus	0.045% max.	0.045% max.
Sulfur	0.030% max.	0.030% max.
Silicon	1.00% max.	1.00% max.
Chromium	18.00-20.00	16.00-18.00
Nickel	8.00-10.50%	10.00-14.00
Molybdenum	-	2.00-3.00%

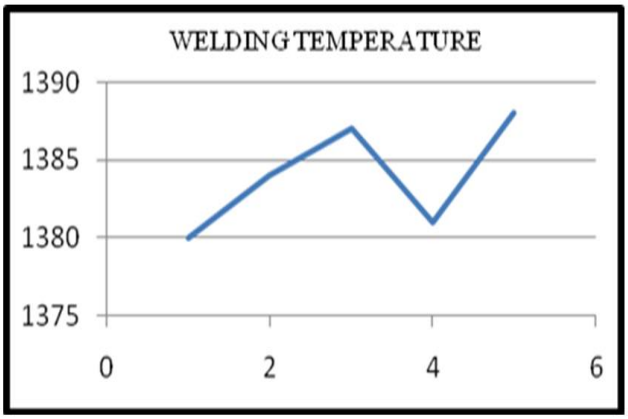
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A. Sample 1

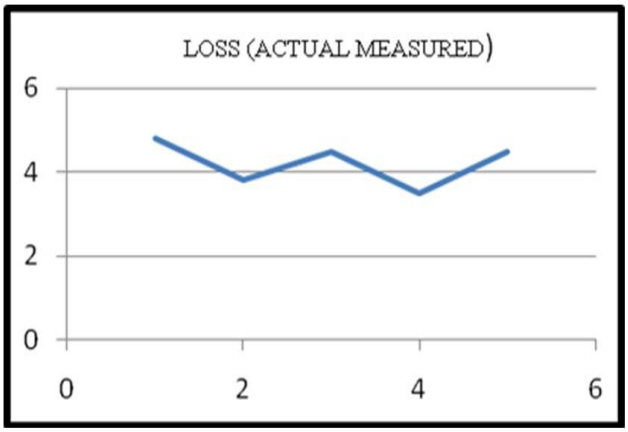
1) Material 1 = Stainless Steel 316
2) Material 2 = Stainless Steel 316 Diameter 1 = 10mm
3) Diameter 2 = 10mm
4) Friction Pressure = 86 kg/mm^2 Feed = 1.2 – 2 mm/min
5) Rpm = 1800

Table 2. SS316 welded Parameters

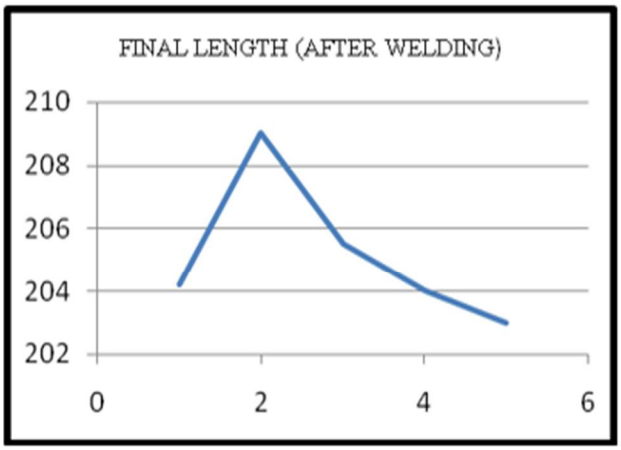
PARAMETERS	1	2	3	4	5
SPINDLE SIDE LENGTH 1	103.5	104	104	104	103
SLIDER SIDE LENGTH 2	105.5	109.2	106	104.5	104
TOTAL (L1 +L2)	209	213.2	210	208.5	207
FINAL LENGTH (AFTER WELDING)	204.2	209	205.5	204	203



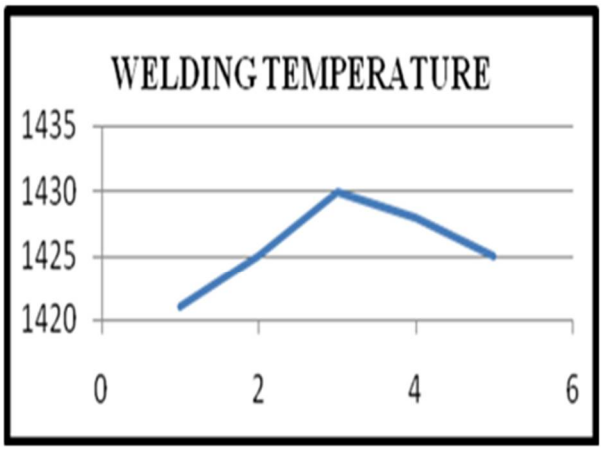
Graph 1. Sample vs. Temperature



Graph 2. Sample vs. loss



Graph 3. Sample vs. Final Length



Graph 4. Sample no. vs. Temperature

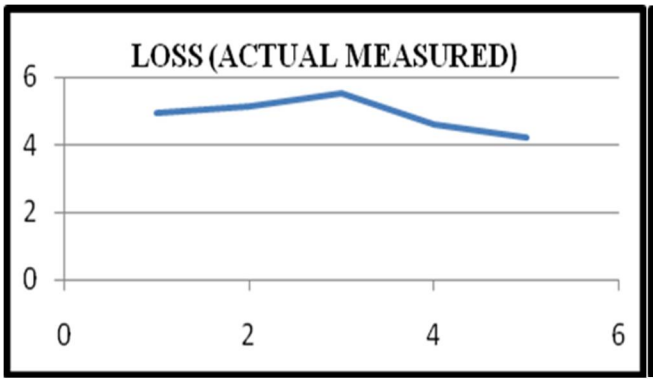
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B. Sample 2

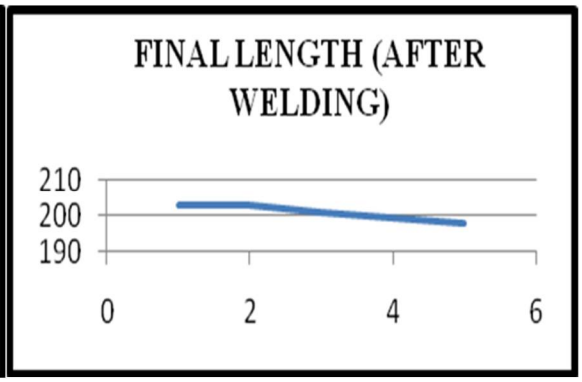
1) Material 1 = Stainless Steel 304
2) Material 2 = Stainless Steel 304 Diameter 1 = 12mm
3) Diameter 2 = 12mm
4) Friction Pressure = 84 kg/mm^2 Feed = 1.2 – 2 mm/min
5) Rpm = 1800

Table 3. SS304 welded Parameters

PARAMETERS	1	2	3	4	5
SPINDLE SIDE LENGTH L1	103.3	103	103.5	103.3	101
SLIDER SIDE LENGTH L2	104.2.	104.5	102.8	100.3	101
TOTAL (L1 +L2)	207.5	207.5	206.3	203.6	202
FINAL LENGTH (AFTER WELDING)	202.6	202.4	200.8	199	197.8



Graph 5. Sample no. vs. loss



Graph 6. Sample no vs. final length

IV. TENSILE TEST RESULTS

To know the breaking load and breaking stress tensile test has done on the rotary welded specimens. For SS316 Diameter 14mm gives better results than SS316 Diameter 10mm. Breaking load test is only conducted for the specimen combination set which is perfectly welded during friction welding experimentation. Since all the samples are perfectly welded Tensile strength of the samples is more at point of weld than the parent material. Load Resolution = Machine Capacity / 20000 Optional On board Extensometer facility with 1 micron resolution & up to 20 mm travel. 20 data set storage (00 to 19) 75 Results Storage (Related to one data set)Data Entry & Parameter selection through Keyboard Non Volatile memory for Result & test data storage.



Fig No 5 Universal testing machine

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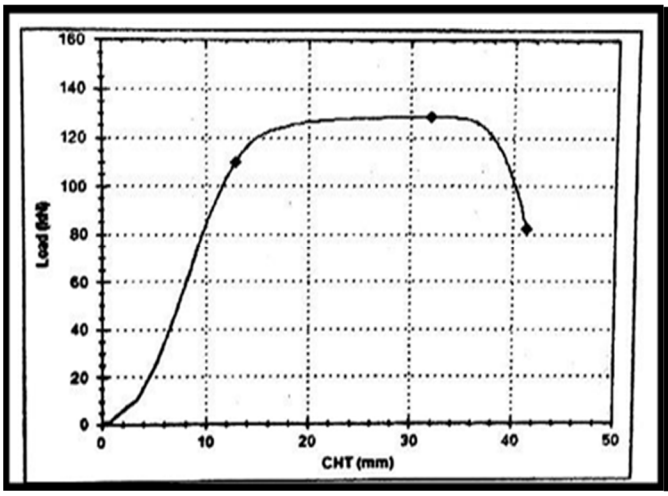
A. Sample-1

1) Material: SS316

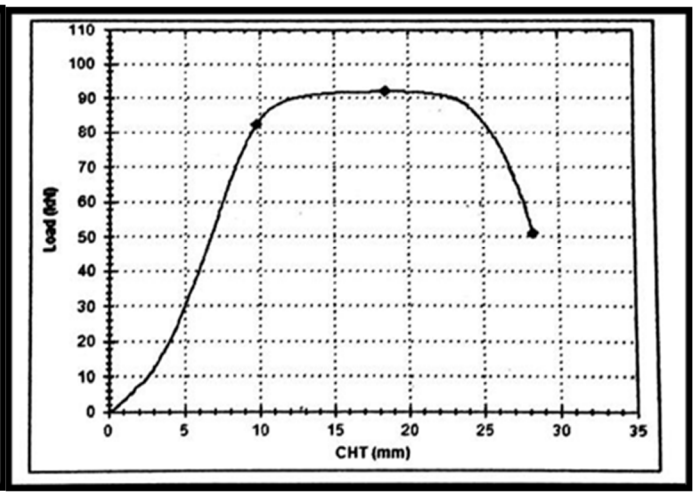
2) Diameter: 14 mm

Table 4: SS316 FWT Reading

MAXIMUM LOAD	1000 kN
MAXIMUM ELONGATION	250 mm
CROSS SECTION AREA	153.928 mm2
FINAL DIAMETER	7.7 mm
FINAL GUAGE LENGTH	250 mm
FINAL AREA	46.57 mm2
LOAD AT YIELD	84.46 kN
ELONGATION AT YIELD	10.00 mm
YIELD STRESS	548.663 N/mm^2
LOAD AT PEAK	104.250 kN
ELONGATION AT PEAK	40.320 mm
TENSILE STRENGTH	677.221 N/mm^2
LOAD AT BREAK	69.980 kN
ELONGATION AT BREAK	47.480 mm
BREAKING STRENGTH	454.599 N/mm^2
% REDUCTION IN AREA	69.75 %
% ELONGATION	16.28 %
YS/UTS	0.81
UTS/YS	1.234



Graph 7. Load vs. cross head travel



Graph 8. Load vs. cross head travel for

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B. Sample 2

1) Material SS304

2) Diameter 12mm

Table 5. SS304 FWT readings

MAXIMUM LOAD	1000 kN
MAXIMUM ELONGATION	250 mm
CROSS SECTION AREA	113.097 mm^2
FINAL DIAMETER	6.16 mm
FINAL GUAGE LENGTH	217 mm
FINAL AREA	29.8 mm^2
LOAD AT YIELD	82.09 kN
ELONGATION AT YIELD	9.800 mm
YIELD STRESS	725.836 N/mm^2
LOAD AT PEAK	91.87 kN
ELONGATION AT PEAK	19.24 mm
TENSILE STRENGTH	812.310 N/mm^2
LOAD AT BREAK	50.920 kN
ELONGATION AT BREAK	28.350 mm
BREAKING STRENGTH	450.232N/mm^2
% REDUCTION IN AREA	73.65 %
% ELONGATION	9.11 %
YS/UTS	0.894
UTS/YS	1.119

V. HARDNESS TEST RESULTS

Rockwell hardness test had done for SS304 using 120-degree diamond cone indenter. Test is done on both Fine polished surface at weld center. The hardness number differs from point to point because of its Heat affected zone properties. Location1 (weld center) is at the center of the weld (for welded pieces). 5mm away from the end from the weld center is point 2A and 2B respectively. 2mm away is point 1A and 1B. Hardness test is carried. Out for this zone.

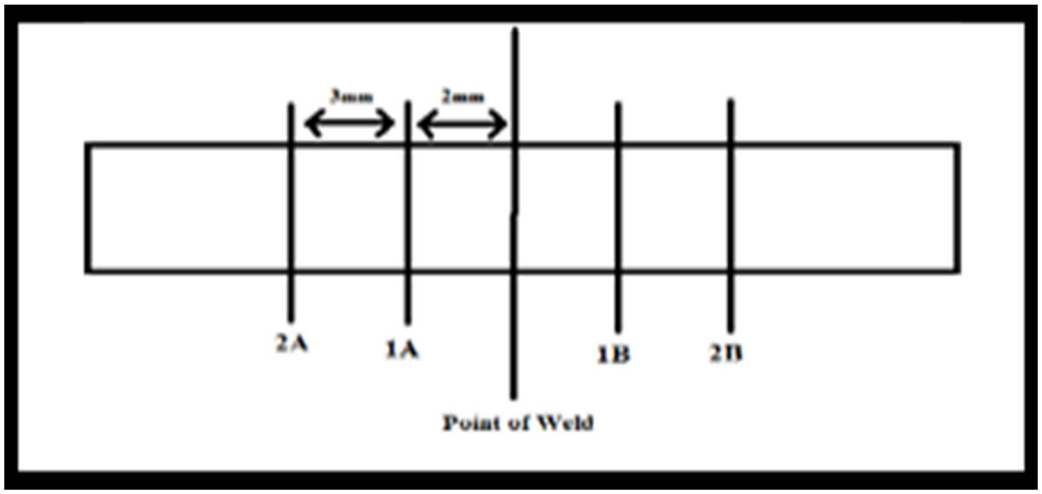
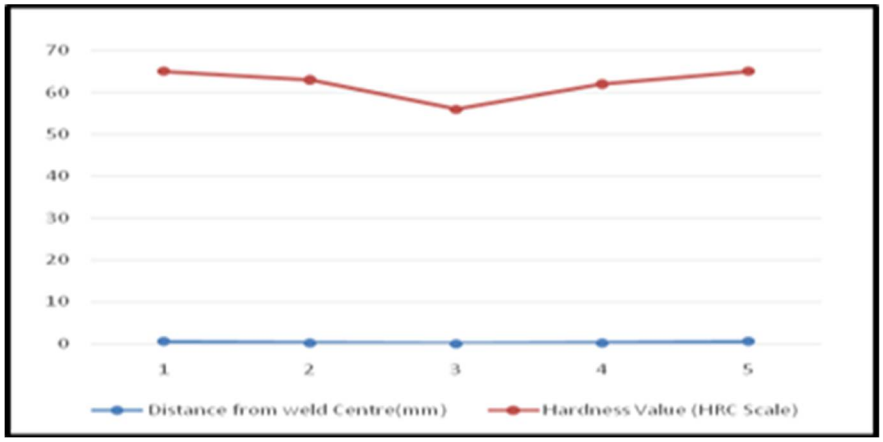


Fig No 6. Indentation locations

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Table 6. SS316 10mm Diameter Readings

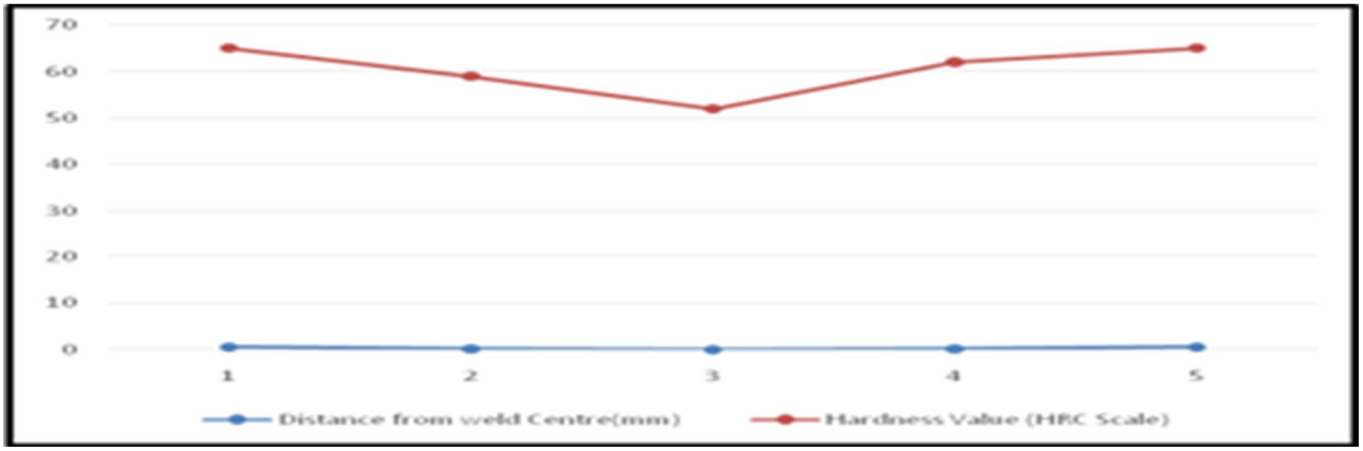
Point Number	Distance from weld Centre(mm)	Hardness Value (HRC Scale)
2A	5	65
1A	2	63
Point of Contact (weld center)	0	67
1B	2	62
2B	5	65



Graph 9. 10mm SS316 Hardness Readings

Table7. SS304 12mm Diameter Readings

Point Number	Distance from weld Centre(mm)	Hardness Value (HRC Scale)
2A	5	65
1A	2	59
Point of Contact (weld center)	0	52
1B	2	62
2B	5	65



Graph 10. 12mm SS304 Hardness Readings

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VI. MICROSTRUCTURAL EXAMINATION FOR GRAIN SIZE EVALUATION

Welded Cross section are first cleaned and polished for examination. After polishing lapping is completed with silicon carbide paper with fineness of 300, 600, 800, 1200, and 1500. After lapping solution is kept in etching reagent for few minutes. Villella's reagent (picric acid 1gm, HCL 5gm, Ethanol 100ml). Now to material is observed under microscope then before testing the material after rotary friction is normalized at room temperature under air cooling.

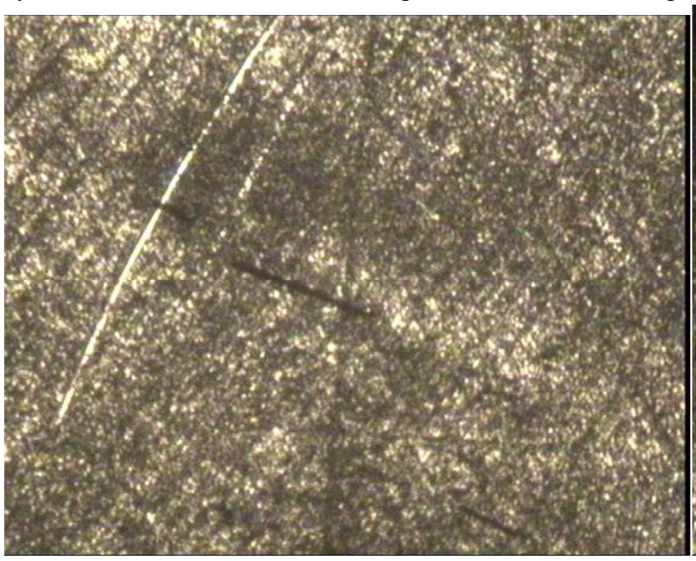


Fig No 7. Free Grain Microstructure SS316 (10mm)



Fig No 8. Weld Joint Microstructure SS316 (10mm)

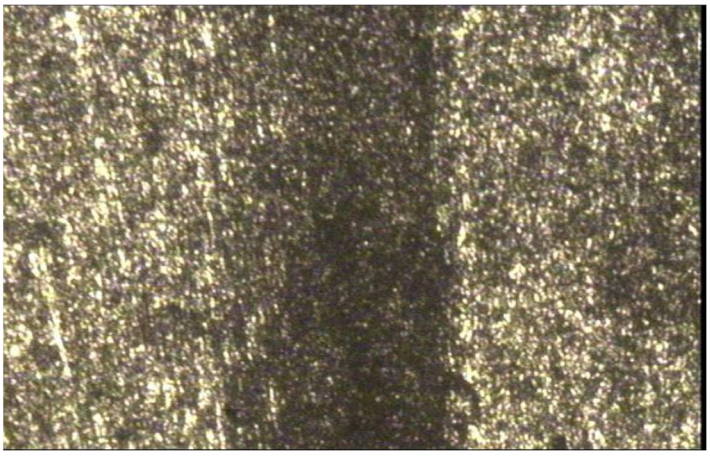


Fig No 9. Heat Affected Zone SS316(10mm)

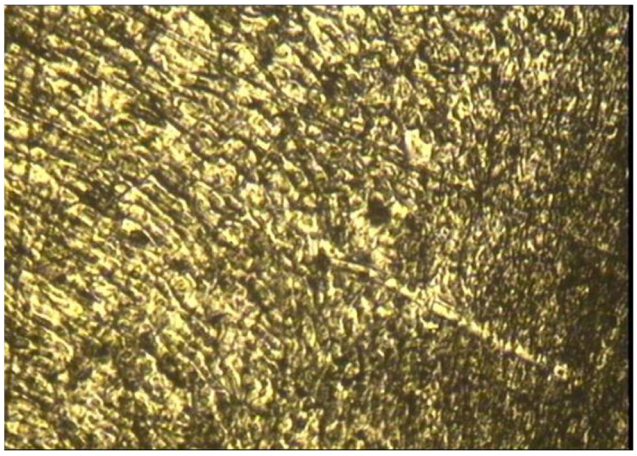


Fig No 10. Free Grain Microstructure SS304 (12mm)

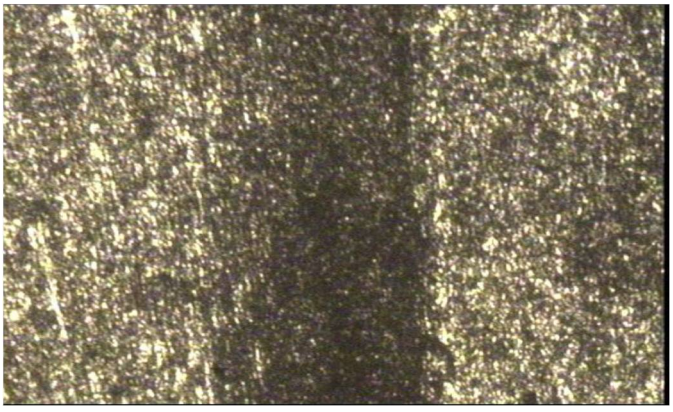


Fig No 11. Weld Joint Microstructure SS304 (12mm)

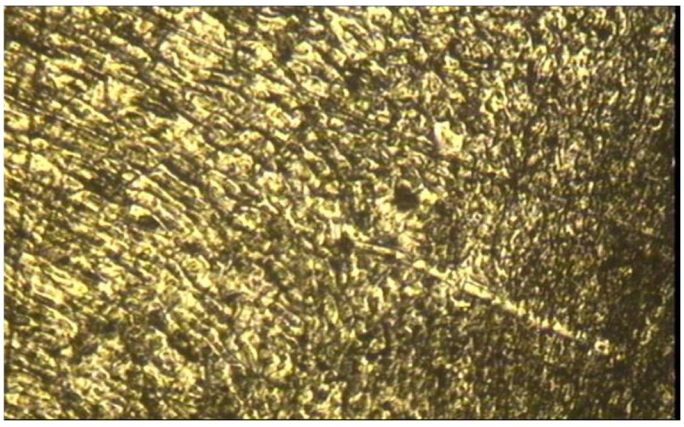


Fig No 12. Heat Affected Zone SS304(12mm)

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VII. CONCLUSIONS

A. Based on Manufacturing Observations

1) For Same Material

- Case 1: SS304 (14, 12)
  As diameter of the sample increase, losses decrease.
- Case 2 SS316 (14, 12)
  As diameter of the sample increase, losses decrease. So, for both materials when Diameter increases loss decreases.

2) For Same Diameter

- Case 1. Diameter 14 (SS304 SS316) SS316 loss is less.
- Case 2: Diameter 12 (SS304, SS304) SS304 loss is less.

So, when comparing for same diameter for these materials, SS304 has less loss at higher diameter.

3) For Same Material

- Case 1: SS304 (14, 12)
  Diameter increases temperature decreases.
- Case 2 SS316 (14, 12)
  Diameter increases temperature decreases.

So, for both materials when diameter increases temperature decreases.

4) For Same Diameter

- Case 1. Diameter 14 (SS304 SS316) SS316 temp is less.
- Case 2: Diameter 12 (SS304, SS316) SS316 temp is less.

So, when comparing for same diameter for these materials, SS316 has less temperature.

B. Based on UTM observations

1) For Same Material

a) Elongation at yield changes with change in the diameter.
b) Greater the diameter greater is the yield elongation.
c) Yield stress is inversely proportional to diameter.
d) Breaking load is directly proportional to diameter.

2) For Different Material

a) Yield elongation for SS304 is more as compared SS316 material.
b) Breaking load for SS316 is less as compared to SS304
c) Yield stress for SS316 is more with respect to SS304 material.

From the tensile test it is observed that the weld is strong enough, the weld joint do not break at the weld joint but instead in the part of sample in bottom chuck of UTM machine. (This is observed from the practical UTM test results.)

C. Based on Hardness Test

1) Considering HRC scale at 150 kgf hardness for SS304 and SS316, Hardness of SS304 is more as compared to SS316 as manganese and nickel percentage is more in SS316.
2) At the point of weld minimum hardness is observed.
3) The hardness value gradually increases with each point of indentation is 0.2 mm for welding contact.
4) With increase in hardness value, Strength, elongation increases.

D. Based on Microstructure Test

Taking under consideration austenitic stainless steel 304 and 316 grade, Temperature, grain structure, pressure and oxidation affects the overall Rotary Friction Welding.

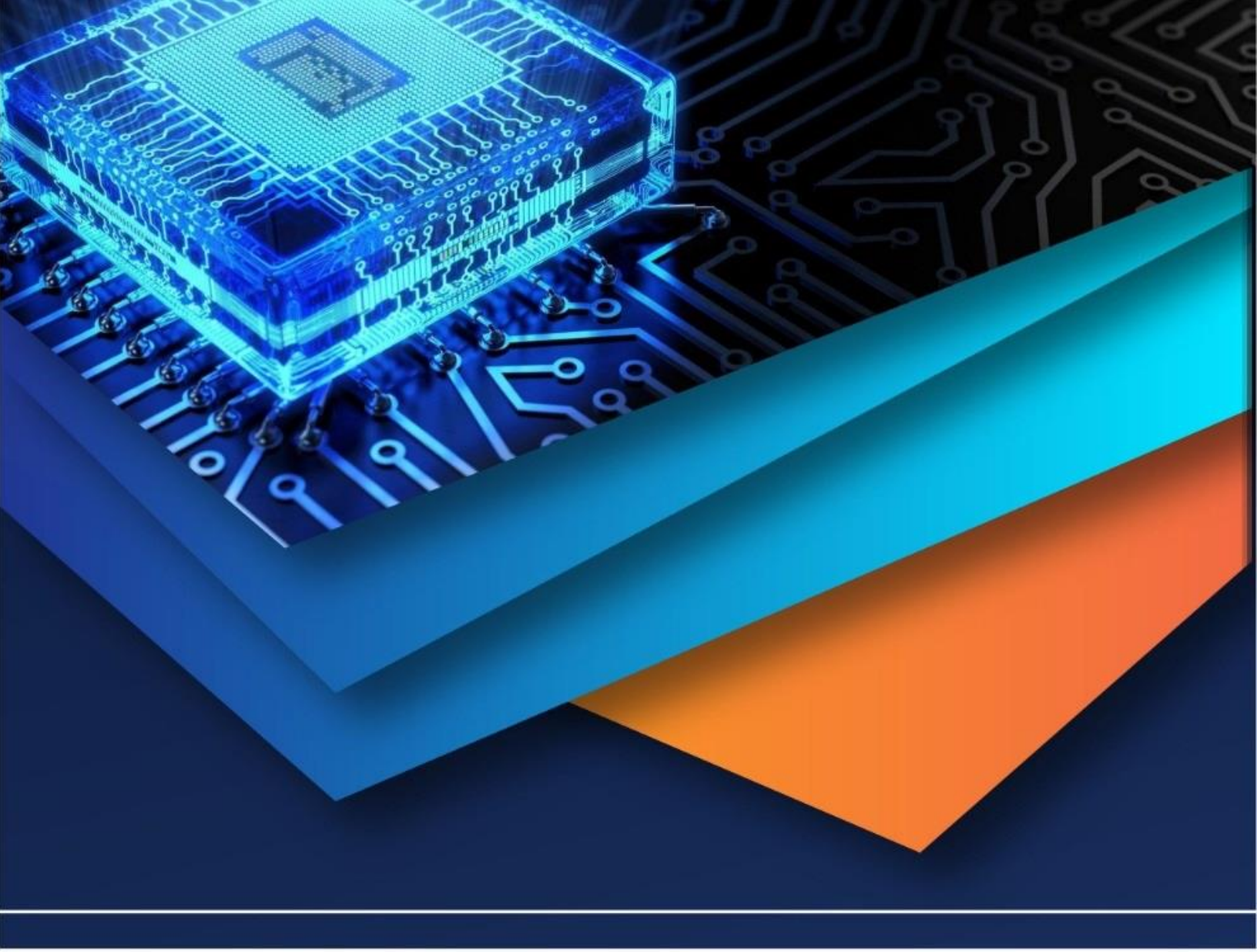
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1) Due to temperature difference austenitic structure is converted into martensitic structure.
2) At low loads, Stainless Steel gets affected by capillary effect due to water percentage at humid atmosphere, this affects friction and wear. High friction is experienced and high humid environment.
3) At high loads capillary effect does not play a considerable role and water acts as a lubricant.
4) In microstructural examination, fine grains are observed at few locations; high wear resistance, smaller weight loss, high hardness, greater tensile strength, yield strength and low coefficient of friction were seen.
5) Oxidation absorption in the presence of water vapour can reduce the rate of oxidation and thus increase wear.
6) Higher the percentage of Nickel and Chromium, higher the percentage of breaking load and elongation.
7) Forging pressure should be more than friction pressure.
8) Grains in welded zone are completely distorted with no twin boundaries with base metals, stringing action is results in dynamic crystallisation which affects the mechanical properties of metals.

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