CHAPTER-5

EVALUATION OF QUALITY OF THE FRICTION SURFACED DEPOSIT
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It is very essential to find the quality of the deposit made by friction surfacing process to determine its suitability for various applications. The mechanical properties need to be evaluated for quantification of the test results useful for design purpose. Since dissimilar metals are involved, selection of test methods poses some difficulty. This is due to wide differences in physical properties of the base metals i.e. rotating consumable and substrate. The conventional tests like tension, shear, bending and hardness can be used for evaluation. It is better to conduct side bend test for the deposits as the bond quality can be better judged.

Hardness survey conducted on the thickness direction gives changes in hardness values due to temperature distribution from the interface on both consumable side as well as substrate side.

Metallographic examination reveals the micro structural changes occurring near the interface on deposit layers and on substrate. Metallographic examination involves study of prepared metal surfaces for microstructural studies using higher magnification to predict the likely behavior of the metal for a particular service condition with reasonable accuracy. It is also possible to establish correlation between hardness and shear energy values, and micro structures of deposit layers and
substrate. Structure at the interface reveals deposit condition whether bond is there or not

5.1 PRIMARY INSPECTIONS

The quality of the deposit is evaluated at the shop floor after deposition. These are for the qualitative analysis, to give status of the deposit, whether it is acceptable or not. The NDT techniques such as appearance and adhesion tests such as lifting test, impact test and chisel and hammer test are performed for evaluation of bonding and quality of friction surfaced deposits.

5.1.1. Visual Inspection

The deposit is inspected for the physical appearance and damage. It is also inspected by visual inspection using magnifying glass for visible defects such as blisters, pits, roughness, and cracks or under cut areas.

5.1.2 Adhesion test

The adhesions are generally used to test the deposit whether it has bond with substrate or not. The following tests are used for the evaluation bond.

When the deposit is rubbed with a scriber using medium force, there is no lifting of the deposit to indicate adhesion.

A sharp tool is used to lift the coating from the base metal. Adherent deposit will not be separated.
The plated surface was subjected to repeated hammer blows of a definite weight or force. But adherent coating is not blistered.

The plated wheel is held against a rough abrasive wheel. Deposit is not pulled out which indicates the deposit having sufficient bonding strength.

A chisel is driven through the heavy deposit by hammer with a moderate force. This is a severe test that indicates weak bonds by separating the deposit from the base metal. The deposit is not separated.

The above test results are summarized and recorded in table 6.1.

5.2 MEASUREMENT OF DIMENSIONS OF THE DEPOSIT.

The width, height and surface roughness of the deposits are not same for all treatment combinations. For each treatment combinations, width and height of the deposit is maximum at initial stage and remains constant while process continues. At the end of the process the mechtrode is automatically detached from substrate by moving upwards. Width of the deposit at this position is small when compared with the remaining length. The surface roughness is also uniform over entire length.

Uneven portion of the deposit is removed from both sides and is discarded. The remaining length is taken for testing purpose. Remaining length of the deposit is divided in to eight equal parts. These segments
are useful for determining average values of the width, height and surface roughness. Similarly mark eight divisions in all deposits.

5.2.1 Width of the Deposits.

The calibrated Mitutoyo Digital Vernier Caliper is used to measure the width of the deposit and its least count of the instrument is 0.02 mm. Mitutoyo Dial Vernier Caliper is available with different sizes. This range of caliper is especially designed for accurate measurement and is anti-corrosive in nature. The instrument which is used to measure up to 300mm x 0.02mm. Vernier calipers are rugged and have long lasting accuracy, are coolant proof, are not affected by magnetic fields, and are largely shock proof. They may have both centimeter and inch scales. Dial calipers are comparatively easy to read. Accuracy of measurement when using a caliper is highly dependent on the skill of the operator.

The surfaces of the bead are cleaned and put them on the surface plate. Widths of deposit are measured at eight marked positions and the average value gives the width of bead. Repeated the same for the remaining deposits and these values are shown in table 6.2

5.2.2 Height of the deposit

The height of the deposit is measured with Mitutoyo dial indicator which is shown in figure 5.1, having least count of 0.01 mm. The small knob on the side of the dial indicator holds a clamp that locks the
dial at required place. The small knob is used to rotate the scale freely so that the zero point can be placed at any position that the large hand sweeps. On the right side of the base is a lever which has the effect of turning the magnetic field on and off.

The small knob is used to rotate the scale freely so that the zero point can be placed at any position. Turning the magnetic field off makes it much easier to remove and adjust the base. Substrate plate is cleaned thoroughly on both sides and placed on the table with deposit at upper side. The deposited surface of the substrate is kept parallel to the table surface by measuring height at four corners of the substrate. The deposited plate is firmly fixed to the table and the heights of the deposit are measured at three positions along the width of the deposit near the marked point, and the height of the deposit at three positions along the width of the deposit is measured, and its average is obtained. This value is taken as height of the deposit at that location.

The same procedure is repeated at eight points without disturbing specimen and determined the average height at that location. The average of those averages at these points is found. This value is to take the height of the deposit for treatment combination. Repeated the same for the remaining deposits and these values are tabulated in table 6.4.
5.2.3 Surface Roughness

Surface roughness is measured with surface roughness tester made by Mitutoyo Corporation, Japan. The instrument is resistant to water and dust. It consists of built-in battery, allows approximately 500 measurements to make and 10 measurement results to save. Results obtained can be observed at a glance without doing any further calculations. The measured data can be collected in the form of print outs also. A convenient carrying case is supplied as standard for protecting the instrument in the field. The set-ups, such as change of standards and cutoff lengths, can be made by pressing the relevant buttons after sliding back the top cover.

Substrate is placed over the surface plate and adjusted so that the upper portion of the substrate will be parallel. Surface roughness is measured at three positions along with the length of the deposit by selecting sample length of 0.8 mm and mean value is calculated. The average values of these eight points are taken as surface roughness of the deposit. Repeated the same for the remaining deposits and these values are tabulated in table 6.6

5.3. METALLOGRAPHY

5.3.1 Metallography at the Interface:

The metallography is essential for the study of the structural characteristics at the interface of low carbon steel and stainless steel.
Dial Vernier Caliper

Dial Indicator

Surface roughness tester
Fig 5.1: Measuring devices used for measuring dimensions of the deposit

With this it is possible to predict the likely behavior of the metal for a particular service condition with reasonable accuracy.

This test is conducted as per the standard IS: 7739 Part 1 at the interface towards low carbon steel. A specimen was prepared from stainless steel deposit over low carbon steel substrate for determining metallography. Specimens are ground perfectly to remove the tool marks by using motor driven abrasive belt.

Glass polishing or emery polishing is done by using a series of emery papers and wet polishing operation on polishing machine. Etching is done on the low carbon steel side at polished surface with an etching agent 2% nital solution. The structural details are revealed under microscope. The figure 6.1 shows the microstructure at the interface of low carbon steel-stainless steel deposit on low carbon steel.

5.3.2 Metallography by using Taper Section Method:

The important aspect of the investigation is to study the interface between the stainless steel and substrate. Generally the interface layer is very narrow, an account of the rapid thermo cycle in friction surfacing. In order to able to observe the phases mores clearly, taper angle is 5°45’ corresponding to an additional magnification of 10 in both longitudinal
and transverse direction of the friction surfacing [89]. Metallography is conducted according to the standard IS: 7739 Part 1 for both the specimens. The etchant used for observing the structural feature and its microstructure of that taper section in the as deposited condition is recorded in figures 6.2. The figures 5.2 show the specimens with its drawings used for determining microstructure both in longitudinal and transverse direction.

Fig 5.2: Metallography by taper section method

5.4 QUALITY EVALUATION OF THE DEPOSIT

Any product without quality will not have any market. The quality of the component is assessed through testing and inspection. The evaluation of the quality of the deposit is broadly classified into non destructive testing and destructive testing. Non destructive testing plays a vital role in industry for quality control.

5.4.1 Non Destructive Testing (NDT)
Non-destructive testing methods have limitations for testing dissimilar metal joints. However ultrasonic testing with special probes and equipment can be used to detect the defects at the interface like lack of bonding and any cracks formed after friction surfacing. Surface defects like cracks and voids can be detected by dye-penetrant examination. Radiography technique is normally best suited for the detection of the volumenar kind of defects [79-82].

5.4.1.1 Visual Examination of Deposits

Visual examination reveals surface flaws, and is a valuable indication in weld quality. It is a simple, accessible, low-cost inspection method, but it requires a trained inspector. Further, it can be an excellent process-control tool, help to avoid subsequent fabrication problems and evaluate workmanship. Visual examination only identifies surface discontinuities. A conscientious program of visual inspection before and during welding may reduce costs by exposing surface defects early in the fabrication process. The following features are required to perform visual inspection method.

The most important instrument in visual testing is the human eye. Hence, the visual acuity of inspector is prime importance aspect in visual testing. It can be natural or aided by other instruments like magnifying lenses.
The VT is conducted for all deposits after the completion of friction surfacing to detect gaps, lack of bond, surface cracks, pores etc with eye and also using magnifier and results are recorded in table 6.1

5.4.1.2 Liquid Penetration Test (LPT)

Liquid Penetration Test (LPT) is also generally called as Dye Penetration Test (DPT). In practice, the liquid penetrant process is relatively simple to utilize and control. The major advantages of penetrant testing include, portability, low cost, easy to use. Establishing procedures and standards for the inspection of specific parts or products are critical for optimum end results. It is extensively used for the inspection of wrought and cast products of both ferrous and nonferrous metals, powder metallurgy parts, ceramics, plastics, and glass objects.

Penetrant testing is a simple non destructive testing method for detecting discontinuities that are open to surface such as cracks, seams, laps, cold shuts laminations, porosity and shrinkage.

In the Liquid Penetrant Technique, fluids are applied to the surfaces of the part to examine and allow to penetrate the surface cracks, seems and pores. The penetrants can seep into cracks as small as 0.1µm in width. Two common types of liquids are used for these tests of fluorescent penetrants and visible penetrants.
The basic steps involved in liquid penetrant test technique are pre-cleaning, application of the penetrant, penetrant dwell time and excess penetrant removal methods to spray developer to get important end results.

Dye penetrant test is conducted on the stainless steel friction surfaced deposit according to the standard ASME Sec V SE 165. When developer is applied over the surfaces, no color indication is observed. This indicates that surfaces are free from cracks or voids or holes open to service. This test is conducted to all deposits prior to preparing specimens for tensile strength test, shear strength test, metallographic test, corrosion test and micro hardness test. The specimen shown in fig 5.3 having width 10mm and 100 mm length of deposit is used for performing the dye penetration test. Specimen is ground on all sides and checked for irregularities and separation.

Fig 5.3 Specimen used for performing the dye penetration test.

Then the surface is polished with different grades of emery papers to be free of tool marks. Applied the cleaner over the surfaces and cleaned
with dry cloth perfectly to remove the dust, oil or grease. Penetrant is applied over the surfaces. After the dwell time of 5-10 minutes, surfaces are cleaned perfectly with soft cloth to remove the traces of penetrant. Developer is applied over the surfaces and observed that there is no color indication of the developer over the surfaces.

Hence this test is preferable for detecting any gaps between the deposit and substrate. It is preferable to use to all specimens which are used for determining tensile strength, shear strength and bend test.

**5.5 DESTRUCTIVE TESTING**

Destructive testing is defined as a form of mechanical test of materials whereby certain specific characteristics of the material can be evaluated quantitatively. Since the specimen is destroyed or mechanically changed, it can not be used for other purposes beyond the mechanical test. Main advantages of destructive testing are, reliable and accurate data is obtained and this information can be used to establish standards and specifications.

The selection of test methods poses some problems due to wide differences in physical and mechanical properties of metals i.e. rotating consumable and substrate.

The only tests that appear satisfactory for dissimilar friction welds are hardness, shear strength test, ram tensile strength test [84] and bend
test for evaluation of bond quality. It is better to conduct side bend test for the deposits as the bond quality can be better judged.

Hardness survey conducted on the thickness direction gives changes in hardness values due to temperature distribution from the interface on both consumable side as well as substrate side.

Metallographic examination reveals the micro structural changes that occur near the interface on deposit layers and on substrate establish correlation between hardness and shear energy values and micro structures of deposit layers and substrate.

Corrosion test is also most useful to find its applications in manufacturing pressure vessels and pump bodies for handling corrosive materials.

5.5.1 Tensile Strength Test

5.5.1.1 Specimen preparation for tensile strength test

Ram tensile test is used to determine the tensile strength of specimen. Specimen is prepared in such a way that the deposited material can be separated only by tensile load. While doing the tensile testing, the bearing area of the deposit is kept minimum to facilitate bond area to take tensile load. To prevent the failure of specimen by shear, specimen is designed carefully by using the relation of tensile strength of a material being twice of its shear strength [90].
Specimen is prepared after the width of the deposit material is measured for all treatment combinations. Outer diameter of the deposited material is carefully machined for making a specimen and the minimum diameter hole that can be drilled in deposited material is fixed to avoid failure by shearing.

Fig 5.4: Specimen used for Ram tensile strength
The sample calculations are shown in annexure 2. Deposits are turned with lathe machine to get its outer diameter according to drawing shown in fig 5.4. The geometrical centre is marked for the turned deposit and the axis is transferred for other side of the deposit. Pilot hole is drilled with lathe machine from opposite side of the deposit, having depth equal to thickness of the substrate. With flat drill, a hole of required diameter is bored carefully so that the drill just comes in contact with the deposited material. The same procedure is repeated to make the specimens for all deposits. Identification of each of the treatment combinations is done on the side of the specimen.

All the deposits of eight treatment combinations are tested for dye penetration test according to standard ASME Sec V SE 165. It was found that all deposits are free from surface defects such as voids, holes and cracks.

Internal and external diameters of the deposit are measured to determine its contact area with substrate and values are tabulated in table 6.8.

5.5.1.2 Design and manufacturing of Ram

Ram is prepared with tool steel and the diameter is equal to diameter of the drilled hole ensuring sliding fit with proper length of the ram to avoid buckling. The figure 5.5 shows the drawing and the ram manufactured for determination of tensile strength of the deposit.
5.5.1.3 Fixture Design and Manufacturing

A special fixture is designed and manufactured to hold specimen firmly and also guide the ram properly for performing tensile strength test of the deposit.

The jig consists of a T-slot having width at the top 25 mm is to keep specimen base properly, with deposit portion in a bottom slot of size of 12 mm. Locking screws are provided to fix the specimen firmly while performing testing. The bottom portion of the jig is milled to get parallel surface to the base surface of the specimen after fixing to reduce the
friction between the sliding ram in drilled hole of specimen. The figure 5.6 shows the drawing and fixture manufactured for tensile strength test. By means of slot made in the fixture it is possible to observe the testing operation. Care should be taken to see that deposited material not touched the fixture.

![Fixture used for Tensile Strength Test](image-url)
Fig 5.6: Fixture and its drawing, used for Ram tensile strength
5.5.1.4 Universal Testing Machine

Universal Testing Machine (UTM) of 40 Ton shown in figure 5.7, is a machine designed to test the specimen in tension, compression and shear. The least count of the machine is 0.5 KN.

Fig 5.7: Universal Testing Machine (U.T.M)

5.5.1.5 Experimental work for Tensile strength test

A 40 Ton Universal Testing Machine is used to determine the tensile strength of the bond deposited. The fig 5.8 shows the arrangement of the fixture and ram for determining tensile strength of the deposit.

The jig is placed on the table surface approximately at centre. The specimen is kept with in the slot of the fixture carefully with drilled hole on top side (substrate). Ram is kept in drilled hole and load is applied gradually with lot of care. Ram should be in vertical position, when its
upper surface touches with crosshead. Load was applied carefully, so that the stainless steel deposit has been separated from low carbon steel. The braking load at which the deposit is separated is noted to calculate the tensile bond strength.

![Experimental setup for Ram tensile strength test](image)

Fig 5.8: Experimental setup for Ram tensile strength test.

The tensile strength value is calculated by the ratio of load \( (P) \) applied to bearing area \( (P/\pi d \times t) \). The procedure is repeated for all the specimens and the values are tabulated. Repeated the procedure for all deposits and readings obtained are tabulated in table 6.8. The table 6.9 shows the specimen used before and after tensile strength test.
5.5.2 Shear Strength Test

5.5.2.1 Specimens for Shear Strength Test

Specimen for shear strength test was prepared from the deposits as per standard ASTM 264. Tool and cutter grinding machine with special attachment is used for preparation of specimen.

Fig 5.9 Drawing and specimen used for shear strength test
The dimensions are maintained as per drawing shown fig 5.9 by carefully machining. They are cut with tool and cutter machine with 0.8 mm abrasive cutter. Precautions were taken to get the edges of the deposit perpendicular to the surface of the specimen and maintained the shearing area for each sample is nearer to each other. This procedure is repeated for each treatment combination to prepare the samples. While doing machining care to be taken to get edges of the deposit perpendicular to the surface of the specimen

Measure the contact area of the deposit and identified the treatment combination on it. All the deposits are tested for dye penetration test according to standard ASME Sec V SE 165. It was found that all deposits are free from surface defects such as voids, holes and cracks

5.5.2.2 Design and Manufacturing of fixture

A special fixture is designed and manufactured as shown in figures 5.10 and fig 5.11 to hold firmly, the specimen made according to the standard ASTM 264 for determining shear strength test. The pitch between the screws position are selected to hold the specimen freely. The required gap between the plates is maintained by tensile springs, placed between the plates co- axially with set of screws.

Openings are provided for this jig to observe the behavior of the specimen when it undergoes shear strength test. The fixture facilitates easy and accurate location of specimen for shear test.
5.10 Fixture for holding the sample for Shear Test

Specimen

Fixed plate

Movable plate

Movable plate drawing
Fig 5.11: Drawings of fixture used for Shear strength Test.
5.5.2.3 Testing Procedure

The specimen is kept with in the fixture such that bearing surface of the specimen is kept on the fixed plate (L type). The set screws are adjusted such that the specimen can move freely with in the fixture without tilting when load is applied. The fixture is positioned over the table of the 40Ton UTM centrally. Load is applied gradually over the specimen such that the entire load is transferred to the specimen bonding area. While load is transmitted to the specimen gradually, at certain position the deposit is detached from the substrate. The reading of the breaking load on dial indicator is noted. The shear strength is obtained by the ratio of load applied to bonding area. The test procedure was repeated for the remaining deposits and the values for the shear strength of the bond are tabulated in table 6.11. The table 6.12 shows the specimen used before and after shear strength test.

5.6 CORROSION TEST

In friction surfacing process, the stainless steel is heated to near to its melting point, due to shear action, bond is taking place on the low carbon steel substrate. When the stainless steel is cooled to room temperature, depending its cooling rate, the stainless steel deposit may be subjected to corrosion attack. Hence it is important to test the corrosion resistance of deposit
An important contributing factor in the failure of transition joints in service is the tendency of carbon to diffuse from the low carbon steel into austenite stainless steel at high temperatures. The driving force for the movement of carbon is provided by the presence of strong carbide forming elements such as chromium and molybdenum in the high alloy steel. The chemical affinity of these elements for the carbon makes such “uphill” diffusion possible.

5.6.1 Intergranular Corrosion.

At temperatures above approximately 1035°C, chromium carbides are completely dissolved in austenitic stainless steels. However, when these steels are slowly cooled from these high temperatures or reheated into the range of 425 to 815°C chromium carbides are precipitated at the grain boundaries. These carbides contain more chromium than the matrix does. The precipitation of the carbides depletes the matrix of chromium adjacent to the grain boundary. The diffusion rate of chromium in austenite is slow at the precipitation temperatures, therefore, the depleted zone persists, and the alloy is sensitized to intergranular corrosion. This sensitization occurs because the depleted zones have higher corrosion rates than the matrix in many environments.

The wide differences in the corrosion rate are the result of the differences in the chromium content. With the lower-chromium-bearing
stainless steels, the passive film is more soluble in the acid, and therefore, more metal must dissolve to repair the film.

If the austenitic stainless steels are cooled rapidly to below approximately 425°C, the carbides do not precipitate, and the steels are immune to intergranular corrosion. Reheating the alloys to 425 to 815°C, as for stress relief, causes carbide precipitation and sensitivity to intergranular corrosion. The maximum rate of carbide precipitation occurs at approximately 675°C. Because this is a common temperature for the stress relief of carbon and low-alloy steels, care must be exercised in selecting stainless steels to be used in dissimilar-metal joints that are to be stress relieved.

Welding is the common cause of the sensitization of stainless steels to intergranular corrosion. Although the cooling rates in the weld itself and the base metal immediately adjacent to it are sufficiently high to avoid carbide precipitation, the weld thermal cycle brings part of the heat-affected zone (HAZ) into the precipitation temperature range. Carbides can precipitate, and a zone somewhat removed from the weld becomes susceptible to intergranular corrosion. Welding does not always sensitize austenitic stainless steels.

5.6.2 Testing for Intergranular Corrosion.

The common method of testing austenitic stainless steels for susceptibility to intergranular corrosion is carried out according
standard ASTM A 262. The figure 5.12 is the drawing used making for corrosion test specimen.

Fig 5.12: Specimen with drawing used corrosion test.

The oxalic acid etch test is used for corrosion test. The sample was kept at $650^\circ C$ for one hour. After corrosion test, the microstructure is shown in figure 6.10, showed clear austenite grains free from carbide precipitation at the grain boundaries.
5.7 MICRO HARDNESS TEST BY VICKERS HARDNESS TESTER

In 1925, Smith and Sandland of the United Kingdom developed Vickers Hardness Test which is used for an indentation test that employs a square-based pyramidal-shaped indenter made from diamond. In this test, the force is applied smoothly, without impact, and held in contact for 10 to 15 s. The force must be known precisely according to ASTM E 384 for tolerances.

The microhardness of the stainless steel deposit is measured on a Vickers microhardness tester. The micro hardness tester has an eyepiece and a rhombus shaped indentor to measure the micro hardness of the material. The load on the indentor can be set using a knob on the tester.

Vickers micro hardness tester shown in figure 5.13, consists of the micrometer which works in conjunction with the eyepiece to measure the indentation dimensions. The time of indentation can be set by using the knob on the front panel of the micro hardness tester.

The sample whose micro hardness is to be measured is mounted in phenolic powder and fixed securely on the table. The eyepiece is used to locate the point where the measurement is to be taken and the height of the table is adjusted until a clear image of the specimen is seen in the eyepiece then the table is locked in this height and the eyepiece is removed and the indentor is put in place above the sample.
The time of indentation and the load on the specimen are set to desired numbers and the start button on the front panel of the instrument is turned on. The indentor indents the material and leaves a rhombus shaped dent on the surface of the sample. The indenter is then pushed back so that the eyepiece is right on the sample.

For the Vickers test, both the diagonals are measured and the average value is used to compute the Vickers pyramid number. ASTM Specification E384, states that the load range for microhardness testing is 1 to 1000 gf. For loads of 1 kgf and below, the Vickers hardness (HV) is calculated with an equation, wherein load \((L)\) is in grams force and the mean of two diagonals \((d)\) is in millimeters:

\[
HV = \frac{2L \sin (136/2)}{d^2} = 185.4 \times \frac{L}{d^2}.
\]
Micro hardness survey is conducted across the interface of stainless steel deposit over the low carbon steel according to standard procedure IS 1501-2002 with Vickers Hardness tester. A deposited plate is shown figure 5.15 was made for performing micro hardness along longitudinal and transverse direction of the deposit.

![Specimen used for micro hardness test.](image)

**Fig 5.14:** Specimen used for micro hardness test.
Specimen was cut from the substrate and ground well to remove the tool marks and surface irregularities of material. Dye penetration test was conducted to ensure that the specimen is free of cracks, or voids.

Hardness survey is conducted on the specimen in longitudinal and traverse direction of the weld by applying 1 kg load with Vickers Hardness tester. The micro hardness values are on the specimen were taken at the interface and its both sides, in longitudinal and vertical direction. The values are tabulated in the table 6.16

5.8 BEND TEST.

Bend specimens have been called "a poor man's tensile test." Though it does not show the quantitative values associated with a tensile test, a bend test will demonstrate both the quality of the deposit and its overall ductility. A bending test, also known as bend test, is used to determine the strength of a material by applying force and seeing how it reacts under pressure. The bend test measures ductility and used to evaluate the quality of materials by their ability to resist cracking or other surface irregularities during one continuous bend.

After the bending test is over, the material is examined to see how well it holds its shape once the pressure is removed, and whether or not the material cracked when pressure is applied.
A special machine/UTM is used to perform the guided bend test. The material must be able to bend up to a specific angle, such as 180 degrees for example, without any cracks appearing. If this happens, the weld will pass the test.

ASTM E290, ISO 7438, and JIS Z2248 describe the requirements of the bend testing for ductility of metallic materials. After bending, the convex surface of the bend is examined for evidence of a crack or surface irregularities. If the specimen fractures, the material fails the test. If the material shows cracks on the bent side, this shows the material holds better against compression than tension.

The bend test assists in determining the soundness of the deposit, the deposit junction and the heat affected zone. Any cracking of the metal will indicate the defective penetration. The stretching of the metal determines to some extent its ductility. Fractured surface shows the crystalline structure.

Types of Bend Tests are broadly be categorized as Root bend test, Face bend test and Side bend test. The specimen is bent by the movement of a plunger or former. In a face bend test the specimen is placed with its face down. If upon examination, cracks greater than three mm appear in any direction, the deposit is considered to have failed. Face bend tests are used to inspect the weld for defects.
In a Root bend test the specimen is placed in the jig with the root down or in just the reverse position of the face bend test. The results must show no cracks to be acceptable. Root bend tests are used primarily to determine the degree of weld penetration. In side bend test, which is a severe test the deposit undergoes compression and expansion simultaneously.

5.8.1 Bend Test Procedure

Three samples were made to meet the requirements of the standard for performing the bend tests. Latter the specimens were ground on all sides to get the parallel and smooth surfaces.

Dye penetration test is conducted to ensure that the specimens were free of cracks, or voids. The figure 5.4 shows specimen and fig 5.15 is shows the jig used for conducting bend tests.

Universal Testing Machine (U.T.M) of 40 Ton capacity with least count of 0.1 KN is used for the bend test and the load applied on the specimen measured on graduated scale. Samples were loaded up to a bend angle of $180^0$ in three cases as described previously.

5.8.2 Face bend test

In the face bend test the deposit on the specimen is under tension during the loading. Test result shows that the bond is strong up to
90°, 120°, and 180° bend. The Bond is satisfactory and no cracks are found. The fig 6.13 shows the specimen after face bend test.

5.8.3 Root bend test

In the root bend test, the deposit on the specimen is under compression during the loading. The figure 6.13 shows the specimen after root bend test. Test result shows that the bond is strong up to 90°, 120°, and 180° bend. The Bond is satisfactory and no cracks are found.

5.8.4 Side bend test

In the side bend test the deposit on the specimen is under tension and compression while bending. The deposit undergoes severe loading.
conditions. Test result shows that the bond strength is strong up to 90°, 120°, and 180° bend. The Bond strength is satisfactory and no cracks are found. The figure 6.13 shows the specimen after side bend test.

5.9 DEPOSIT ANALYSIS USING REGRESSION EQUATIONS

The results such as width, height, surface roughness, shear strength and tensile strength (responses) of the stainless steel deposits are obtained by using these eight treatment combinations. The regression equations for these responses are discussed and analyzed.

The basis of approach is the assumption of a simplified linear model for the optimization parameters given by

\[ \eta = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots \ldots \ldots \ldots \text{ etc.,} \]

Where \( X_1, X_2 \ldots \ldots \ldots \text{ etc.,} \) are the factors on which \( \eta \) depends and \( \beta_0, \beta_1, \beta_2 \ldots \ldots \ldots \text{ etc.,} \) represents the true values of the corresponding unknown coefficients. Each coefficient represents the influence of the corresponding factor on the quality of the deposit expressed by the optimization parameters. From the results of an experiment comprising a finite number of trials, one can arrive at a simple estimates of the coefficients \( \beta \), which are then usually fitted into linear regression equation of the type

\[ y = b_0 + b_1 X_1 + b_2 X_2 + \ldots \ldots \ldots \ldots, \] where \( y \) is the response function and the \( b \)’s are the “estimated” values of the \( \beta \)’s. In terms of
the friction surfacing, the response function \( y \) is the magnitude representing the physical characteristics of the deposit such as width, height and surfaces roughness, or bonding strength of the weld like tensile strength and shear strength. \( X_1, X_2 \ldots \ldots \ldots \) are the factors in friction surfacing on which the response depends.

The values obtained for the response function \( y \) in each of these \( 2^3 \) experiments are to be analyzed statistically for estimating the regression coefficients and then fitting a prediction equation for the optimization. ANOVA table [85] is constructed to test the significance of the parameters and to find the coefficients. Test of significance is carried out and the regression equation arrived at after identifying appropriate coefficients for various responses.

5.10 EFFECT OF PROCESS PARAMETERS ON FRICTION SURFACED DEPOSIT.

\( 2^3 \) factorial designs of experiments is selected to optimize welding conditions. The experimental design matrix indicating the eight treatment combinations are represented in eight vertices of rectangular prism according to the suitable scale and is shown in figure 6.13. This is known as response surface methodology indicating the responses in the order on the eight vertices of the solid for eight treatment combinations. These responses are width, height surface roughness, shear strength and tensile strength respectively. The optimum parameters can be selected
within the volume of the prism for getting desired properties of the deposit. The following conclusions are arrived at after trend analysis of parameters on each of the responses as indicated in table 6.17.

For the range of the process parameters of frictional pressure (29-49 MPa), rotational speed (1500-2500rpm) and welding speed (78-190 mm/min), to obtain higher values of height (1.5 mm), width (12.0 mm), tensile strength (420Mpa) and shear strength values(120 MPa), the selected process parameters derived from the diagram are frictional pressure 39 MPa, rotational speed of the mechtrode 1950 rpm and welding speed 120 mm. Suitable Process parameters of the deposit can be selected depending on its applications by using this approach.