EXPERIMENTAL INVESTIGATION ON HEAT TREATED TI-6Al-4V WELDED JOINTS BASED ON TRIBOLOGICAL AND NON DESTRUCTIVE TECHNIQUES

Srinivasreddy Vempati [1] , V.Gopinath [2], M.Srinivasulu [3], U.Hari Babu [4] , K. Chandrasekhar [5]
[1,2,3,5] Associate Professor, Department of Mechanical Engineering QISCET, Ongole
Professor, Department of Mechanical Engineering QISCET, Ongole
Corresponding author email-vempati.srinivas@qiscet.edu.in

ABSTRACT
Ti-6Al-4V (grade 5) It is a high strength-to-weight alpha-beta titanium alloy. It is one of the most widely used titanium alloys and is employed in a variety of low density applications There is need to study tribological properties of heat treated Ti-6Al-4V welded joints. Our project deals with the tribological properties (Corrosion, Wear), NDE tests (Radiography, Dye-Penetration, Ultrasonic Testing), Mechanical test (Tensile test) on Ti-6Al-4V(Grade-5) material welded joints. The corrosion test should be performed on base metal (before heat treated),annealed metal(after heat treated) and comparing these two for the best; The wear test will be performed on base metal of Ti-6Al-4V, heat treated metal metal(annealed) and on welding region for welded joint of base metal before heat treated and the readings will be noted. The radiography test is to verify the internal structure of the body. The dye-penetration will be performed on Ti-6Al-4V welded joint for knowing the cracks developed on welded region. The tensile test will be performed on Ti-6Al-4V welded joint to know the mechanical property (Tensile). The ultrasonic test will be performed on Ti-6Al-4V welded joint.

Key words**:** Dye penetration, optimal sensitivity**,** Ultrasonic testing, wet chlorine, protective film

INTRODUCTION

Ti-6Al-4V (Grade5) has predominant characteristic such as excellent corrosion resistance, good weight to strength ratio when compare to steel, toughness, having low thermal expansion rate, the cruciform welded joints made with Ti-6Al-4V are used in civil industries, military vehicles, bridge girders, nuclear engineering, space vehicles and aerospace are subjected to fatigue loads to occurrence of small cracks to grow and slowly the cracks propagate and finally component will fail. Titanium alloy offers certain advantageous characteristics, including high surface tension, low thermal conductivity, low density, and good weld pool fluidity. These qualities make it possible to weld with an unsupported root surface and minimize weld geometry flaws.

Since tungsten has the greatest melting point and does not burn up during welding, Kumar and Sundarrajan recommend using tungsten or tungsten alloy as the electrode material for GTAW (2013). The electrodes can range in length from 75 to 610 millimetres and in diameter from 0.5 to 6.4 millimetres. Nearly all GTAW applications use filler metals as well, with the main exception being welding thin materials. The current carrying capability of filler materials depends on the polarity type and comes in a variety of diameters. Manual filler metal feeding is also an option for proper welding. A shielding gas, usually argon or helium or occasionally a mixture of argon and helium, shields the weld region from the atmosphere.
TIG welding is one of the best methods adopted to join the Ti-6Al-4V compare to all other welding joints majorly for the plates having more than 5 mm thickness. It is more economical and able to weld all different positions which can produce high quality welds. It is more significance in industry because of no spatter of weld is occurred.

Tribology research ranges from macro to nano sizes and is conducted in a variety of domains, including the movement of continental plates and glaciers as well as the mobility of animals and insects. The traditional focus of tribology study has been on the manufacturing and transportation industries, however this has greatly expanded. The following areas of tribology research can be broadly separated into them, however there is considerable overlap.

The friction pair was slid during the testing at a velocity of 0.3 m/s on an 8 mm radius. A 400 m sliding radius was decided upon. Tribological tests are conducted at room temperature and at greater temperature (150 °C), as Ti6Al4V alloy is used to generate elements working at high temperatures. A thermocouple that was positioned 2 mm from the friction surface area was used to measure the temperature. However, the actual temperature can rise to much higher levels. The temperature, friction force, and the following three parameters' values all changed throughout the tests.

A.B. Short et al[1] made an effort to investigate the feasibility of microstructural characterization and gas tungsten arc welding of titanium alloy plates. Studies on the mechanical characteristics and Thin commercially pure titanium sheets were automated TIG weld structures were characterized by A. Karpagraj et al [2]. Because titanium and its alloys are prone to the oxidation process, welding them presents a number of challenges to the designer. A very new sort of shielding system is being tested to combat this pollution.

The proposed arrangement and design have been used to join sheets of commercially pure titanium using different welding current and travel speed settings for the GTAW technique. On thin sheets with a 2mm thickness, bead on plate (BoP) tests were carried out by altering the process variables. Images of the macrostructure were then taken. These findings are used to determine the process parameters for creating full penetration butt joints on titanium sheets that are 2 & 1.6 mm thick. They investigate the effects of these GTAW parameters on the surface appearance, mechanical properties, and microstructure at the cracked areas of the welded joints.

S Maya-Johnson et. al [3]The cooling rate has an impact on the corrosion behavior of a hot wrought Ti-6Al-4V extra-low interstitial alloy, according to S Maya-Johnson et al. (see reference 3). The Ti-6Al-4V extra-low interstitial alloy, which is frequently utilized as a biomaterial, is discussed in this study's discussion of the impact of the Effects of forging process cooling rate on corrosion behavior and microstructure. The samples were hot forged in the dual phase field (+) at two different temperatures, and tests were run at a constant strain rate of 4*10-3s-1.

The samples are cooled in three distinct cooling mediums (water, air, and clay), and scanning electron microscopy was used to examine the microstructure (SEM). In Ringer's solution at 37°C, cyclic polarization experiments were used to measure the corrosion resistance. It was possible to compare the outcomes for forged and commercial samples in order to determine some correlations between cooling rate, microstructure, and corrosion resistance. Effects of e-beam welding on thick titanium alloy Ti6Al4V were studied by Jos Mathew et al. They ran every test to look at the welding quality and strength.

EXPERIMENTAL PROCEDURE

TIG welding is one of the best methods adopted to join the Ti-6Al-4V compare to all other welding joints majorly for the plates having more than 5 mm thickness. It is more economical and able to weld all different positions which can produce high quality welds. It is more significance in industry because of no spatter of weld is occurred.

To create the joint, TIG welding operations are used, along with multi-pass welding techniques. Lack of

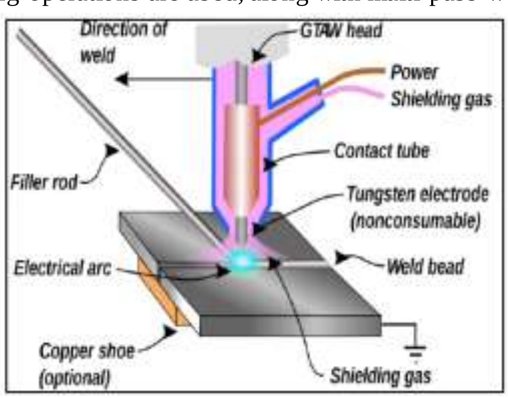


Fig 1. TIG welding

penetration is caused by the identical construction of all the fillet welds creating the joint, which results in an unfused space between the two fillets. Titanium is very reactive toward air gases such nitrogen, oxygen, carbon, and hydrogen, generating significant embrittlement, making welding problematic at 550^{0c} and typically in the molten stage. By designing the fixtures, the welding of specimens is done and to avoid distortion among the weld plates arrangement of fixtures is necessary.

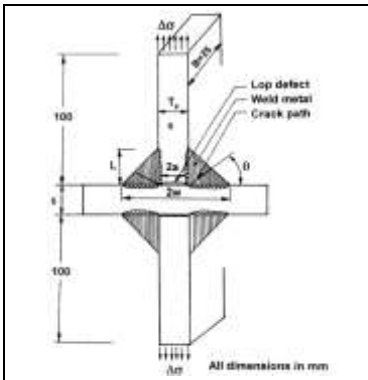
Figure 2 shows dimensions of cruciform shape weld specimen with load carrying welds and geometrical parameters are represented. The specimens have a main plate that is 100mm x 24mm x 6mm in size and two cross plates that are each 100mm x 24mm x 6mm in size. Then, using the TIG welding method, fillets were formed between the flange plate and the cross plate laying weld metal.

Table 1 Welding parameters

Welding current	80-85 amp
Filler material	ER Ti-5
Shielding gas	Argon
Heat input	1.20 kJ/mm
travel speed	62 mm/min
Voltage	10-12 volts
Filler material dia	1.5 -2 mm
Type of shielding	Argon
Shielding gas flow	8 -6 lit /min
Electrode	Tungsten

Table 2. Mechanical properties of Ti-6Al-4V

Tensile strength	895 MPa
Poisson's ratio	0.31
Yield strength	750 MPa
Elastic modulus	112 GPa
Shear modulus	42 GPa
Elongation at break	14%



Dimensions of Cruciform shape of welded joint As per AWS D1.1

TIG welding of cruciform shape joints

cruciform shape specimen

Fig 2. Fabrication of Cruciform shape weld joint

The Base Metal's chemical composition was determined using an optical emission spectroscope (OES). The base metal sample is lit at various spots, and the spectrum of the sparks is examined to estimate the alloying elements.

Fig.3. Optical Emission Spectroscopes

Table 3.Alloy elements in Ti 6Al4V	
Element	Content (%)
Carbon, C	0.074
Iron, Fe	0.132
Aluminum, Al	6.130
Vanadium, V	4.020
Titanium, Ti	89.14

RADIOGRAPHY TEST

Industrial radiography is a non-destructive testing technique that can be used to repeatedly examine manufactured parts to confirm their interior integrity and structure. Either X-rays or gamma rays can be used to perform industrial radiography. Both kinds of radiation are electromagnetic in nature.

According to the associated certified a weld map for any metallic welding and casting that may be necessary to meet the requirements of the specification or other guidelines being used to create and manufacture the component, this Procedure defines the general requirements for radiographic inspection (RT). For the XXX Project, which will be manufactured in YYY, this radiographic testing technique covers the necessary materials, calibration, equipment, personnel qualifications, examination process, assessment, records, and acceptance requirements.

According to T.222.2, the result of any radiographic testing due to surface irregularities being unable to conceal or confuse the appearance of any discontinuity. Surface imperfections on the inside (where accessible) and outside, including those caused by welding, must be eliminated using any method that is appropriate. All butt-welded joints must have a completed surface that is level with the base material or that has relatively uniform crowns, but reinforcement must not be more than that allowed by the referencing code section.

RADIATION SOURCE: -

The radiography testing methods must show that required radiography sensitivity has been attained. RADIATION SOURCE: X-Radiation. 300 KV is the maximum x-ray voltage.

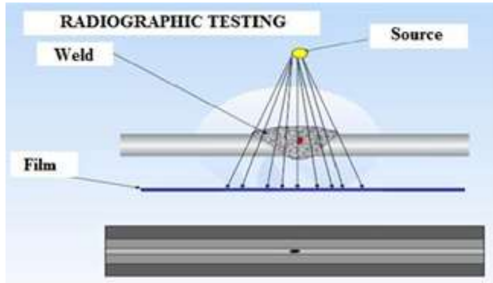


Fig.4.Radiographic Testing

When doing radiography, a single-wall exposure method must be used whenever practical. A double-wall procedure must be used when using a single-wall radiographic testing approach is impractical. An adequate number of exposures must be done in order to demonstrate that the required coverage has been reached.

Single-Wall Approach: During a single-wall radiographic test, radiation only reaches one wall of the weld (material), which is visible on the radiograph and used to assess the acceptability of the test result.

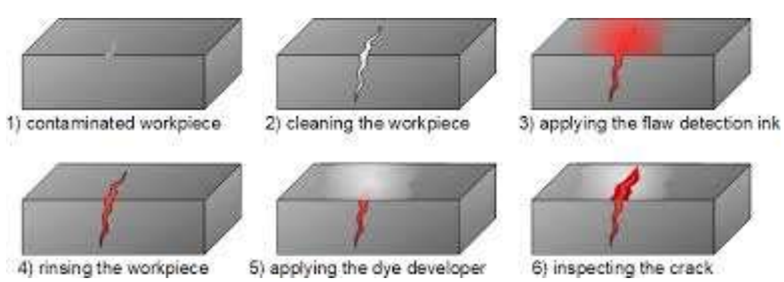
Double-Wall Method One of the following double-wall approaches must be employed when a single-wall method is impractical.

(A) Viewing on a single wall. A method that allows the radiation to travel through two walls while only allowing the weld (material) on the wall with the film to be seen for approval on the radiograph can be utilized for materials and for welds in components. When full coverage of circumferential welds is required, a minimum of 3 exposures at an angle of 120 degrees from one another must be made.

Double-Wall Viewing is (b) For materials and welds in components with a nominal outside diameter of 312 in. (89 mm) or less, a method can be used where the radiation passes through two walls and the weld in both walls is examined for acceptability on the same radiograph. The only IQI that may be utilized for double-wall viewing is the source-side IQI. It is important to take precautions to prevent exceeding the necessary geometric un sharpness. Single-wall viewing must be employed if the geometric un sharpness criteria cannot be met

DYE PENETRATION TEST

Apply developer on the other side of the weld to check for any through and through defects. Interpretation & evaluation of the discontinuity indications shall be carried out after developer time of min. 10 minutes & max. 60 minutes. For the examination and evaluation of indicators, a minimum light intensity of 100 ft candles (1000 lux) is needed to provide optimal sensitivity. Excess penetrant on the face after the necessary penetrant dwell time. For the examination and evaluation of indicators, a minimum light intensity of 100 ft candles (1000 lux) is needed to provide optimal sensitivity. Excess penetrant on the face after the necessary penetrant dwell time. All traces of lint shall be removed. It is not permitted to clean the surface with water after applying a penetrant and before developing. The component surface must be permitted to dry by normal evaporation & a drying time of minimum 30



seconds shall be allowed prior to application of developer.

Fig 5.Dye Penetration Test

Application of developer on the face side to check surface defects shall be by spraying to assure complete coverage with a thin & even film. After removing excess penetrant, developer must be applied as quickly as possible, but no later than 10 minutes. Interpretation & evaluation of the discontinuity indications shall be carried out after developer time of min. 10 minutes & max. 60 minutes.

ULTRASONIC TESTING

The physical properties of Ti-6Al-4V alloy is having low density 4.43 gm/cm^3, melting point 1674^{0}c, low thermal conductivity and high surface tension. Now a day's application and utilization of heavy thickness plate of titanium alloy (Ti-6Al-4V) is increased. Fusion welding of titanium alloy has less strength for thick plates and hence it is not suitable. Therefore, the filler metal is added to titanium alloy plates and The grade of titanium being welded is typically matched to the filler-metal composition. High strength grades of unalloyed titanium and high yield filler metal are utilised during welding to increase joint ductility. For GTAW of titanium alloy, the typical tungsten electrode types (EWTh-1 or EWTh-2) are utilized. To improve the arc initiation and spread of the arc, the size of electrode is governed by the smallest diameter and the electrode diameter size is depend upon weld current.

Ultrasonic testing is A hardness test, tensile test, and fatigue test are performed on all specimens with faults in welded joints, a small number of specimens are rejected because it is discovered that the welded regions have fractures, and specimens without defects are put through these tests.

Ultrasonic testing uses high frequency sound waves, typically between 0.5 and 1.5 MHz. to carry out inspections and take measurements. In addition, it is frequently used in engineering applications (such as material characterization, dimension measurements, and flaw detection/evaluation). Ultrasonic testing typically relies on the collection and measurement of either the reflected waves or the transmitted waves (pulse-echo) (through transmission). Both of the two are used in some situations, although pulse echo systems are frequently more advantageous because they only require access to one side of the item being researched.

A typical pulse echo Ultra sonic inspection system as shown in Fig 3.5 consists of several functional units, such as Under the control of the pulser/receiver, an electronic device that can generate high voltage electrical pulses, the transducer generates high frequency ultrasonic energy Where sound energy is introduced, spreads through objects, and takes on waves. When the wave path breaks, some of the energy will be reflected from the fault surface (like a crack). The signal's journey time can be computed from its velocity to determine how far it travelled after the transducer transforms the reflected wave signal into an electric signal that is displayed on a screen. Sometimes information on the position, size, direction, and other features of the reflector can be obtained from the signal.

In ultrasonic testing, the object being tested is moved over by an ultrasound transducer connected to a diagnostic tool. Frequently, as in immersion testing, a couplant (like oil) or water is used to separate the test object and the transducer. However, couplant is not necessary when ultrasonic testing is carried out with an Electromagnetic Acoustic Transducer (EMAT). A flaw coming from the right side produces a third indication while also weakening the back-wall signal. The ratio D/E, as indicated in Figure, determines the depth of the defect

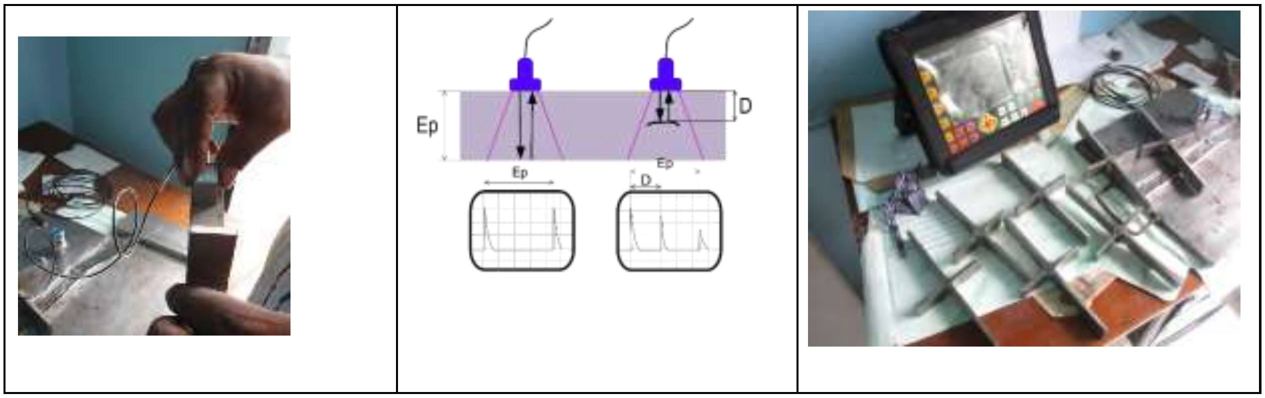


Fig 6. Ultrasonic Testing Procedure

WEAR TEST

From a material standpoint, the test is carried out to assess a material's wear property and decide whether it is suitable for a particular wear application. Wear tests are conducted from the perspective of surface engineering to assess a certain surface engineering technology's capability to reduce wear for a particular application, as well as the ability to analyse how treatment conditions (processing parameters) affect wear performance in order to reach the best possible surface treatment conditions.

A wear testing device is sometimes known as a tribometer or wear tester. Tribo- is a prefix that stands for wear, friction, and lubrication. There are a lot of different wear testing setups and processes that are used in labs all over the world and are described in technical literature, perhaps more than several hundreds. A wear tester will always comprise two components that are loaded against and moved comparatively against one another, regardless of how drastically different one arrangement is from another. An electro-magnetic device or a motor can power the movement.

PROCEDURE

- Check whether the work piece holder moves from right to left
- Check whether the roller is rotating in clock wise direction with 40 rpm
- Attach the workpiece to the workpiece holder
- Stick the energy paper (Grade 60) around the roller
- Switch on the motor
- Make sure that the workpiece should get in touch with roller of emery paper
- Initially add 1 kg load on workpiece
- Pass the workpiece along the length of roller while moving the roller
- After the full completion of 1 pass we will find out the wear measurement
- Repeat the same procedure by applying 1 kg load on workpiece and pass along the length of roller.

Fig 7.Wear Testing Equipment

CORROSION TEST

Due to a passive oxide film, titanium, a highly reactive metal, exhibits outstanding corrosion resistance in oxidizing acid conditions. After being made commercially available in the 1950s, titanium has established itself as a corrosion-resistant material. Commercial-purity titanium is the grade that is most frequently utilised in the chemical industry. It is reliant on an oxide film for its corrosion resistance, just like stainless steels.

This is why it performs best in conditions that are oxidizing, such hot nitric acid. Titanium frequently performs better than stainless steel in environments that encourage pitting and crevice corrosion because its oxide film is more protective (e.g., seawater, wet chlorine, organic chlorides). Although being resistant to some media, titanium is not immune at high temperatures, it can be vulnerable to pitting and crevice assault. For example, if the temperature rises over roughly 110 °C, it is susceptible to seawater corrosion.

Strong titanium has a specific gravity of 4.5 g/cm3, which is in the middle of steel and aluminum. It was first used as a structural material for aero planes and munitions because of its outstanding strength to weight ratio.

Nowadays, titanium is widely used in the chemical process and space sectors. Due to its reactivity, titanium requires a protective coating (TiO_2) in order to withstand corrosion. Because absorbed gases might cause the metal to become brittle, melting and welding must be done in inert settings. Many of titanium's uses in corrosive services are due to three exceptional properties, including: Seawater and other chloride salt solutions Hypochlorite and wet chlorine Nitric acid, including fuming acids.

Fig 8. Corrosion test equipment

Initially clean the salt spraying chamber with distilled water and 600gms of salt is mixed with 12 liter of H_20 and place the solution in one tube, Spray the specimen in salt spraying chamber. Spray the solution on specimen through the sprayer which is connected to solution tube and check the specimen for about every 8 hours of time.

TENSILE TESTING

Following ASTM E8 standards of test techniques for tensile testing of metallic materials, tensile test specimens are tested in a computer-aided, servo-controlled All-purpose Testing Device (UTM). In order to determine a material's tensile properties, such as yield point, maximum tensile strength, breaking strength, percentage of elongation, percentage of area reduction, and rigidity modulus, a tensile test is often performed on the material.. As indicated in the photographic view of the UTM. The load has been mounted and secured between the fixed cross head and the moving cross head, and the pressure valve has been released, causing the moving cross head to travel downward.

The diameter of the cross section was measured using the calipers on each specimen. To measure the distance between the two markings following the tensile test, a gauge length was chosen (usually 50.00 mm) and scribed into the specimen. Figure 1 on the following page displays a typical reduced gauge section specimen. The appropriate material was selected, and the Blue Hill data collecting software was launched. To guarantee that the software only measured the tensile load delivered to the specimen, the load cell was zeroed.

The specimen was placed evenly spaced between the two clamps before being inserted into the Instron load frame's jaws. The reduced gauge section of the specimen was used to attach the axial and transverse extensometers, making sure that the transverse extensometer was over the whole diameter of the specimen and that the axial extensometer was accurately set when attached to the gauge. By taking this precaution, the extensometers are protected and the data are improved.

Fig 9.Tensile Testing of welded joint

RESULTS AND DISCUSSIONS

TENSILE TEST

The tensile test was carried on Ti-6Al-4V welded joint. UTM testing machine is used to conduct the test. Ti-6Al-4V plate (Grade 5) was employed as the specimen in the current study. One main plate and two cross plates have the following measurements: 100 mm long, 24 mm wide, and 6 mm thick. Using ER Ti5 filler rod and a TIG welding machine, the cruciform-shaped plates are joined together using tungsten inert gas arc welding. Rarely are titanium gr-5 plates available. The yield point is 820 MPa, and the specimen fails at an ultimate point of 890 MPa (133 KN and 144 mm2 of cross section).

Fig 10.Stress-strain graph obtained from tensile testing

RADIOGRAPHY TEST

To confirm the internal organization and structural integrity of the specimen, the Ti-6Al-4V material underwent the radiography test. X-rays or gamma rays can be used for industrial radiography as long as the sample is kept between the radiation source and the film or detector. The test was carried out in a lab, and the outcome revealed that REPAIR was required due to lack of penetration.

Table 4 –Parameters in Radiography testing

PARAMETERS	OBSERVED VALUES
sample Details	TIG WELDING WELDED JOINT - Ti-6Al-4V
SS/FC	1x1.5mm
source	Ir; X-Ray Ci; KV=160
penetrometer	DIN 10-16
exposure Time	1 min 30 sec
density	2.0 to 3.0
SFD/FFD, deviation time, deviation temp	24” 3 min 24^{0}c
technique	SWSI
screen in mm	F/B: 0.10/0.15 mm
sensitivity	2%
type of Film	Agfa D4
specification	ASME Sec VIII DiVl

SEGMENT	SIZE OF RADIOGRAPHY	INTERPRETATION	REMARKS
A	4”x5”	Lack of penetration	REPAIR

DYE-PENETRATION

The Dye-Penetrant test was carried out on Ti-6Al-4V material to check the cracks developed on welded region. The test was done by a laboratory and the results was observed.

1. Test Conducted on the sample.
2. No Recordable indication observed.
3. Hence Sample Passed the test.

PARAMETERS	OBSERVED VALUES
Surface Inspection	Clean& free from surface
Cleaner Used	DYCHEK C50 Batch No: 2C 501504- 16.09.2019
Penetrant Used	DYCHEK P50 Batch No: 2P 501506- 19.09.2019
Developer Used	DYCHEK D50 Batch No: 2D 501510- 19.09.2019
Sensitivity Used	The Aluminum panel is used for mentioned batch of penetrant tested for its sensitivity and found satisfactory.
Remarks	[a] Test Conducted on the sample.[b] No Recordable indication observed. [c] Hence Sample Passed the test

CORROSION TEST

The Corrosion test was carried out on Ti-6Al-4V material for Before Heat treatment and After Heat treatment pieces on sea environmental condition (Salt spray test) by keeping the samples in salt water for about reaching it to the white rust formation. The test was done by a laboratory and the equipment standards was ASTM B117. We kept the two samples for about 120 hours and there is no Rust formation for both samples (White or Red Rust) till 120 hours. Then the material we chosen was well and good for both samples. The sample size was (80x25x6mm).

TEST REPORT FOR BASE METAL

PARAMETERS SALT SPRAY TEST	TEST METHOD: - ASTM B117 RESULTS
[1] 24 HOURS	NO WHITE OR RED RUST FORMATION NOTICED
[2] 48 HOURS	NO WHITE OR RED RUST FORMATION NOTICED
[3] 72 HOURS	NO WHITE OR RED RUST FORMATION NOTICED
[4] 96 HOURS	NO WHITE OR RED RUST FORMATION NOTICED
[5] 120 HOURS	NO WHITE OR RED RUST FORMATION NOTICED

The Wear test was carried out on Ti-6Al-4V material, A Scratch/Wear/Abrasion Resistance tester equipment is used to conduct the test. Initially the sample was connected to a shaft and the shaft which is placed on roller (abrasion particle). The roller is connected to motor similarly the shaft with sample slides over the roller. The roller rotates at 40rpm. The wear rate will be finding out after on complete slide of sample on roller. The Wear test was carried out for 3 samples mentioned below

1. Base Metal of Ti-6Al-4V (Before Heat Treated).
2. Annealed Heat Treated (Flat Rectangular Piece)
3. Welded Region (After Heat Treated)

From the obtained values we observed that the wear rate of Base Metal (Before Heat Treated) is high compared to Annealed Heat-Treated metal, welded area of annealed portion. Finally, the Heat-Treated welded region having less Wear Rate.

Sample	Initial Weight(g)	Final weight (g)	Abrasion loss(g)	%
Base Metal	10.0664	9.7146	0.3514	3.49
Annealed Heat-Treated Metal	5.0659	5.0196	0.0463	0.91
Welded Area (Annealed)	5.2146	5.1771	0.0375	0.72

ULTRASONIC TESTING

High frequency sound waves (usually in the range of 0.5 to 1.5 MHz) are used in ultrasonic testing (UT) to carry out inspections and take measurements. In addition, it is frequently utilized in technical applications (such as material characterization, dimension measurements, and fault detection/evaluation). Ultrasonic testing typically relies on the acquisition and measurement of either the transmitted waves (pulse-echo) or the reflected waves (through transmission). Both of the two types are employed in certain applications, although pulse echo systems are typically more beneficial because they only need access to one side of the object being studied.

All specimens with flaws in the welded joints are subjected to ultrasonic testing; a small number of specimens are rejected when cracks in the welded regions are discovered; specimens without defects are subjected to hardness, tensile, and fatigue testing.

CONCLUSION

Compared tribological properties for both Heat treated, Before Heat treated Ti-6Al-4V material. No rust formation is noticed for two samples for about 120 hours. For Wear test the heat-treated welded region having high wear resistance capacity compared to remaining two samples.

- Lack of Penetration with Repair is needed was observed for welded joint by Radiography test
- No recordable indications are observed at the time of dye-penetration test on Ti-6Al-4V welded area region
- Specimen is failed at the yield point of 820 MPa and the ultimate point of 890 MPa (133 KN and 144 mm2 of cross section, respectively).

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