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Parametric Optimization of TIG welding and Defect Identification using Non Destructive Testing Methods

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ABSTRACT: This paper aims to study about the process of tungsten inert gas welding and the defects arises on the TIG welding using various non destructive testing methods. TIG welding is the one of the most popular gas – shielding arc welding process used in many industrial fields. In this investigation the optimization of process parameters of tungsten inert gas (TIG) welding of ASTM A36 carbon steel is done. Various non destructive testing methods are carried out to identify the defects on the TIG welding specimens. Non destructive testing methods are the wide group of testing methods used to evaluate the properties of a material , component or system with out causing damage. in this study visual inspection, liquid penetrant inspection, radiography testing, and ultrasonic testing is used to identify the defects in the weld samples.

KEYWORDS: Tungsten inert gas welding, Non destructive testing methods.

I.INTRODUCTION

Welding is the intricate process of uniting two metal components by applying intense heat, pressure, or a combination of both, causing the metals' weld region to liquefy and form a permanent bond. Essentially, a non-consumable tungsten electrode is utilized to facilitate the fusion of multiple metals by concentrating heat in a specific area and transferring it through conduction to the surrounding parent metal. This method is commonly employed in joining sheet metals, where electrical energy is converted into light energy, passing through flux to the electrode, initiating an arc. The arc's light energy transforms into heat energy, enabling the welding operation to commence. A successful welded joint is achieved when two meticulously cleaned surfaces are brought into contact with each other, and either pressure, heat, or both are meticulously applied to achieve a durable bond. Tungsten Inert Gas (TIG) welding, also known as Gas Tungsten Arc Welding (GTAW), is a widely utilized welding technique, particularly suitable for joining similar or dissimilar materials and various metal alloys. This process involves the utilization of non-consumable tungsten electrodes, which generate an arc to melt the metals while simultaneously introducing a filler wire to reinforce the bond. Additionally, an inert gas, such as helium or argon, is employed to shield the welding environment, safeguarding the molten weld pool from atmospheric contaminants.

Non-destructive testing (NDT) is a crucial set of techniques used to examine materials and components without causing any damage. These methods allow for the detection and characterization of surface and internal defects without altering the material's original properties. In simpler terms, NDT involves inspecting materials or components to find flaws or defects without changing them or causing harm. NDT methods are cost-effective and can be used for individual sample inspection or as part of a larger quality control system in production. Various NDT techniques, such as visual inspection, liquid penetrant testing, magnetic particle testing, radiography, and ultrasonic testing, are essential for evaluating casting parts and ensuring their quality meets standards.

II. LITERATURE REVIEW

1)Optimizations of TIG Welding Process Parameters on Angular Distortion of Stainless Steel 301 Alloy Weldments, Author - A. Balaram Naik and A. Chennakesava Reddy, The paper examines TIG welding parameter optimization, highlighting Experiment 8's key findings: 3mm root gap, 150 Amps current, 1.6mm electrode diameter, 5 L/min gas flow. Heat affected zone shows superior hardness. Angular distortion minimal with 1mm root gap but increases with higher currents and smaller electrode diameters. Experiment 8 has highest Signal-to-Noise ratio for hardness. Austenite higher in weld zone, ferrite in

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heat affected zone due to carbon enrichment. Emphasizes weld and heat affected zones' increased hardness compared to base metal, notes challenges of angular distortion, suggests remedies like mechanical or thermal straightening.

2) Experimental and Numerical Optimization of Tungsten Inert Gas (TIG) Welding Process Parameters Relative to Mechanical Properties of AISI 1018 Mild Steel plate, Author - Aniekan Essienubong**,** Study used Design Expert in RSM for TIG welding, aiming to optimize weld variables for desired outcomes. 20 runs maximized UTS and yield strength while minimizing elongation. Run No. 8 parameters applied and tested. Results showed correlations between predicted and experimental outcomes, with increased gas flow, speed, and voltage leading to higher strength and lower strain. Welded joint stronger than parent metal due to electrode interactions and chemical reactions in weld pool.

3) Detection of Weld Metal Defects using DT and NDT -A Review, Author - Prajapati Vraj, Jaiswal Ayush, Patil Yash, Panchal Hardik, M.A. VOHRA, The utilization of Destructive Testing (DT) and Non-Destructive Testing (NDT) is increasingly accepted in industrial applications and NDT systems, particularly for detecting weld defects. Both techniques offer distinct advantages and limitations. DT is valuable for determining strength and hardness properties of weld metals. Various NDT techniques are employed for detecting defects in both outer and inner surfaces of materials. Each NDT method has unique capabilities and limitations in detecting weld joint surface defects. Further research is expected to enhance the characterization of material surfaces in this area.

4) Real Time Non-Destructive Testing Methods of Welding, Author - Paul Kah , Belinga Mvola , Raimo Suoranta, This work reviews three non-destructive testing methods - real-time radiography, eddy current, and ultrasonic - and their variations for weld inspection. Each method detects discontinuities both on and beneath the surface. Real-time radiography detects interior flaws like cracks, porosity, and incomplete penetration, but has limitations regarding operator skill, radiation hazards, and fillet weld inspection. Eddy current devices, based on impedance variation, offer fast and sensitive detection of small cracks, but are limited in penetration depth and can only detect surface-disrupting cracks. Ultrasonic testing, with better wave penetration, detects deeper defects and offers real-time inspection through techniques like TOFD and phase array scanning, applied in various applications such as pipeline inspection.

III. MATERIALS AND METHOD

3.1 weld sample preparation

Commercial carbon steel plate ASTM A36 of thickness 6 mm was selected as work piece material for the present experiment. carbon steel plate was cut with dimension of 200 mm x 100 mm with the help of band-saw and grinding done at the edge to smooth the surface to be joined. After that surfaces are polished. The initial step involves edge preparation of the experimental specimen, groove angle made in the base metal is 37.5 degree. Which helps to provide optimal fusion of weld joints. the machine used in this experiment is SAI TIG200 Amos, which is an inverter type dc welding machine. Zirconiated Tungsten electrodes E7018 of diameter 2.4 mm was taken as electrode for this experiment. The end of the electrode was prepared by grinding the tip of the tungsten electrode. the filler material used in the welding is 70S2 with a diameter of 2.4 mm. the shielding gas used in this welding is 99.99% argon gas. For the experiment of welding parameters selected are shown in table 3.1

Si no	Gas flow L/Min	Welding current A	Voltage V	Travel speed mm/Min	Root gap mm
1	10	75	9-11	60-70	2
2	13	85	9-11	60-70	2
3	15	75	9-11	60-70	2
4	10	85	9-11	60-70	2
5	13	75	9-11	60-70	2
6	15	85	9-11	60-70	2

Table 3.1 selected parameters for TIG welding

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3.2 Visual inspection

Verification of material specifications and dimensions is conducted based on the applicable drawing. Additionally, edge preparation and weld fit-up are verified in accordance with the applicable drawing and Welding Procedure Specification (WPS). The welding surface must be devoid of scale, rust, oil, grease, slag, detrimental oxides, and other contaminants. Fit-up alignment is ensured using steel rules and spirit levels, while groove angle and root gap are confirmed using templates. The use of correct welding consumables are verified through the WPS. Moreover, weld surfaces are inspected for finish and cleanliness, and fillet welds are assessed using fillet gauges. The weld surface is inspected after welding for surface discontinuities such as crack, porosities, pinhole, etc. While as-welded surfaces are acceptable, weld surfaces must be sufficiently smooth, without coarse ripples, grooves, overlaps, ridges, or valleys. Finished welds must be conducive to accurate interpretation during radiographic and other non destructive examinations. Additionally, fillet weld surfaces should seamlessly integrate with the joined surfaces for optimal quality and integrity.

3.3 Liquid penetrant testing

STEP 1 - Pre cleaning

The surface must be clean from oil, water, dirt or other contaminants they prevent penetrant from entering the flaw. In this experiment SKC-1 cleaner from MAGNAFLUX is used as the cleaning agent, shown in figure 3.1. The cleaning agent is directly applied to the surface to be inspected and wiped with clean cotton cloth to remove contaminants. And wait until dry the surface before applying the penetrant.

Fig 3.1 SKC 1 cleaning agent.

STEP 2 - penetrant application

Once the surface has been thoroughly cleaned and dried the penetrant material is applied by spraying, brushing, or immersing the part in the penetrant bath. MAGNAFLUX brand SKL-SP1 is the penetrant used in this experiment, shown in figure 3.2. SKL-SP1. After applying penetrant to weld surface waited until the penetrant is entered to the flaws

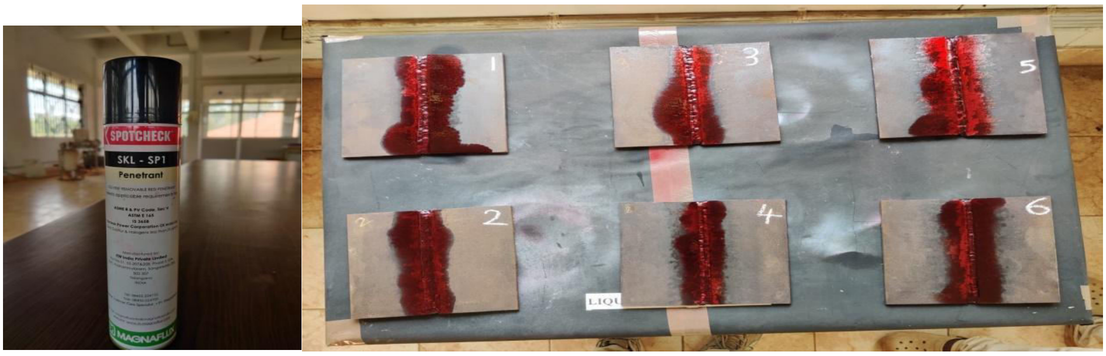

Fig 3.2 SKL-SP1 penetrant and test samples after penetrant application.

STEP 3 - penetrant dwell time

The penetrant is left on the surface for a sufficient time to allow as much penetrant as possible to be penetrate into a defect. Here in the case of SKL-SP1 penetrant dwell time is 10 min. the penetrant is left on the specimen surface for 10 min for better absorption.

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STEP 4 - Excess penetrant removal
This is the one of the most important step of the inspection procedure because the excess penetrant must be removed from the surface of the sample while removing as little penetrant as possible from defects. In this experiment cleaning agent is sprayed to the cotton cloth and wiped the excess penetrant left on the surface of the specimen.

STEP 5 - Developer application
A small layer of developer is then applied to the sample to draw penetrant trapped in flaws back to the surface where it will be visible. In this experiment MAGNAFLUX brand SKD-S2 is used as the developer shown in figure 3.3. It is a blend of inert inorganic particles suspended in an isopropanol and acetone mix. The SKD-S2 developer is applied directly to the specimen surface. And wait until the dwell time.

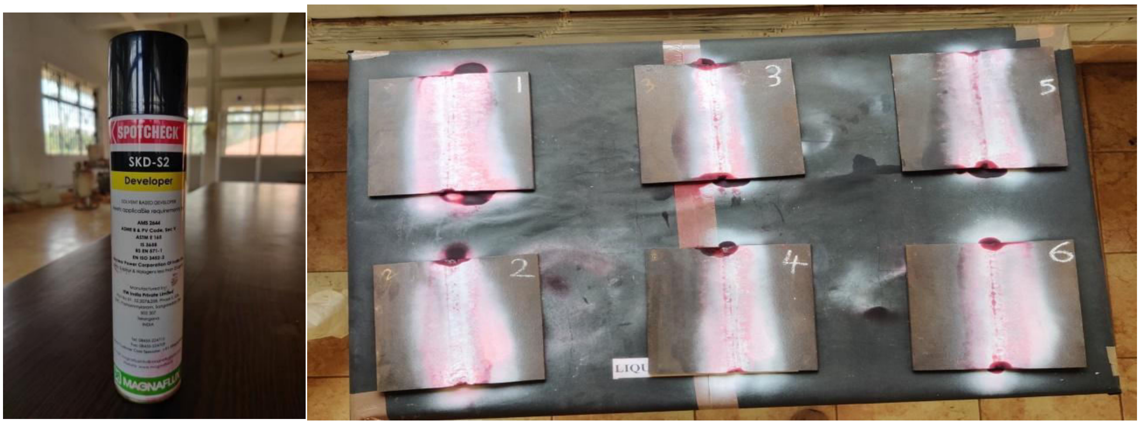

Fig3.3 SKD-S2 developer and test samples after developer application.

STEP 6 - Developer dwell time
The developer is allowed to stand on the surface for which the penetrated penetrant is come out and visible on white contrast developer. In this experiment after applying developer waited for 10 min for developing indications.

STEP 7 – Inspection
Inspection is the process of finding out the defects in the test specimen. The inspection process is carried out under appropriate lighting.

STEP 8 - post cleaning
The final step in the process is to clean the surface. The post cleaning process has been carried out by applying the cleaning agent and then wiped by the cotton cloth.

3.4 Ultrasonic testing
Scanning surfaces shall be smooth and free from foreign matter likely to interfere with probe coupling (e.g. rust, loose scale, weld spatter, notches, grooves). irregular surface of the test surface shall not result in a gap between the probe and test surfaces greater than 0, 5 mm. miniature angle-beam calibration block (v2) is used for calibration. The miniature angle-beam block is primarily used in the field for checking the characteristics of angle- beam transducers. In this experiment MODOSONIC ARJUN 30 plus is used as the ultrasonic unit. It is a ultrasonic testing machine which have a range of 2.5mm to 10 meter test range. The probe is selected accordance with the thickness, if plate thickness is in between 0 and 30 mm 70 degree angle probe is used, if thickness is in between 30 and 40 mm 60 degree angle probe is selected, if thickness is garter than 40mm 45degree angle probe is used. In this experiment plate thickness is 6mm so 70deagree angle probe is selected. 4 MHZ frequency is selected for inspection process. A suitable couplant is selected to avoid air gap between test specimen and probe surface. It is very important that the same couplant is used throughout the whole testing procedure. In this experiment oil is used as the couplant. Longitudinal defects are found by directing the sound beam normal to the length of the weld and moving the transducer back and forth to scan the entire weld. The transducer is oscillated through a small angle. Back and forth motions should be repeated at regular intervals which do not exceed 80% of the width of the transducer as the probe is moved   weld. Also ensure that probe travel speed not to exceed more than 150 mm/s. False indications occur regularly, these are due to mode converted waves, arising from the object geometry, and must be correctly evaluated and ignored. This is the most difficult part in the whole process of ultrasonic testing. The next step is to draw the inspection sketch. This should clearly display the probe movement area,

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the part of the weld covered by the inspection, and the point where the ultrasonic beam is introduced to the part. On the tested object, the zero point of the measurement should be permanently set and marked on the sketch. The indications which are not accepted should be marked during the inspection. Before finishing and leaving the inspection site, couplant and other test residues should be removed.

FIG 3.4 ultrasonic flaw detector.

3.5 Radiography testing

Two of the most commonly used sources of radiation in industrial radiography are x-ray generators and gamma ray sources. Industrial radiography is often subdivided into "X-ray Radiography" or "Gamma Radiography", depending on the source of radiation used. The radioactive "capsule" is attached to a cable to form what is often called a "pigtail''. The pigtail has a special connector at the other end that is attached to a drive cable. A device called a "camera" is used to store, transport, and expose the pigtail which containing the radioactive material. The camera contains shielding material which helps to reduces the technicians exposure to radiation during use. A hose-like device called a guide tube is connected to a threaded hole called an "exit port" in the camera. The radioactive material will leave and return to the camera through this opening when performing an exposure. A "drive cable" is connected to the other end of the camera. This cable, controlled by the technician, is used to force the radioactive material out into the guide tube where the gamma rays will pass through the specimen and expose the recording device. Single wall single image technique (SWSI) is employed in this testing. The gamma ray source used for this radiography testing is IRIDIUM192 (ir192) with a strength of 10 curies (10ci). The size of the gamma ray source is 2.7 mm × 2.9 mm. The film used for the testing is AGFA D7. A 20 Inches of source to film distance (SFD) is fixed for producing proper exposure rate. 5 minutes of exposure time is given to produce sufficiently exposed radiography film. A lead screen of thickness 0.1mm in front and back is used for cutting of the low intensity scattered radiations. The weld surface irregularities shall be removed by any suitable process to such a degree that the images of surface regularities cannot mask or be confused with the image of any discontinuity on the resulting radiograph. The test specimen is place in between gamma ray source and film. The required source to film distance is fixed. And exposure process is carried out for required time. After exposure the film is developed, Processing shall be done manually in air conditioned and dark room free from light leakages.

Fig 3.5 radiography testing machine.

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| Volume 7, Issue 5, May 2024 |

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IV. RESULT

4.1 Visual inspection.

Fig 4.1 visual inspection result of test sample 5.

A small pinhole defect is found on the test sample 5. Remaining samples are free from surface.

4.2 Liquid penetrant testing.

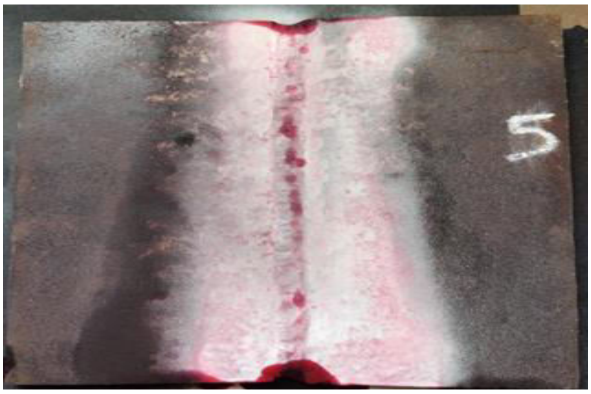

Fig 4.2 liquid inspection test result of test sample 5

A small pinhole is found on the test specimen 5. The remaining samples where free from surface defects. No other defects are found on liquid penetrant inspection. Lots of falls indications are obtained in liquid penetrant inspection.

Fig 4.3 test sample which showing falls indications.

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4.3 ultrasonic testing.

Test sample 1

Fig 4.4 ultrasonic test result of test sample 1.

A porosity of 28mm size and 1.45 mm lies on a depth from upper surface is found on test specimen 1. The porosity is 120 mm away from edge A and up to 150 mm.

Test sample 2

Fig 4.5 ultrasonic test result of test sample 2.

A porosity of 2mm size and 1.34 mm and lies on a depth from upper surface is found out in test specimen 2. The porosity lies on 25 mm away from edge B.

Sample 3

A lack of fusion of 5mm size and lies on a depth of 3.82mm from upper surface is found out on test specimen 3. This defect lies 90mm away from edge A.

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Fig4.6 ultrasonic test result of test sample 3.

Sample 4

Fig 4.7 ultrasonic test result of test sample 4.

A lack of fusion of 5mm size and lies on a depth of 3.41mm from the top surface is found on the test specimen 4. This lack of fusion is 80mm away from edge A. also an under cut is found out 55mm away from edge A.

Sample 5

Fig 4.8 ultrasonic test result of test sample 5.

Two Lack of fusion found on test sample 5. first one is size of 2mm and lies on a depth of 3.41mm from top surface and 125 mm away from the edge A . second one is size of 3mm and lies on a depth of 4.21mm from top surface and 160mm away from edge A.

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Sample 6

Fig 4.9 ultrasonic test result of test sample 6.

In test specimen 6 two porosities are found. First one is 20mm size and lies on a depth of 1.75 mm from top surface and 25mm away from edge A. the second one is a size of 3mm and lies on a depth of 3.41 mm from top surface and 175mm away from edge A.

4.4 Radiography testing

Sample 1

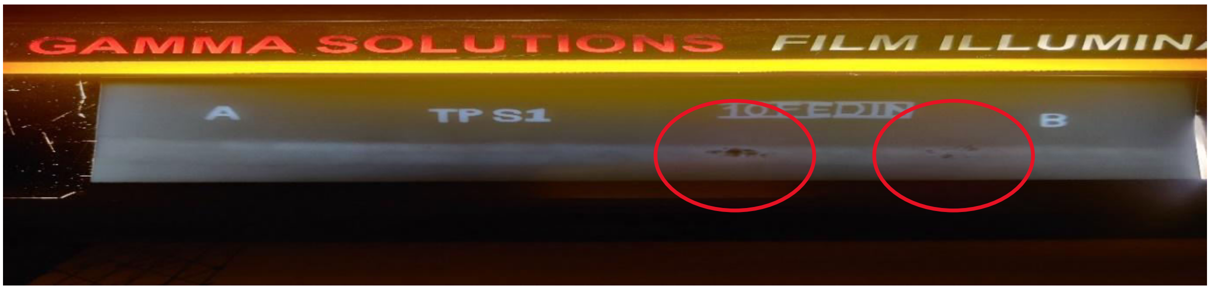

Fig 4.10 radiography test result of test sample 1.

A cluster porosity of 20 mm length is identified on the test specimen 1.Which is not acceptable.

Sample 2

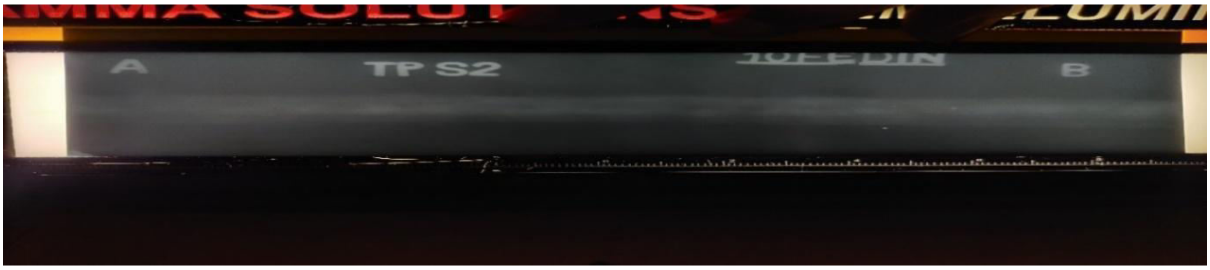

Fig 4.11 radiography test result of test sample 2.

A porosity of 0.2 mm is identified on test specimen 2. Which is in acceptable in range.

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Sample 3

Fig 4.12 radiography test result of test sample 3.

No significant defect is identified on the test specimen 3.

Sample 4

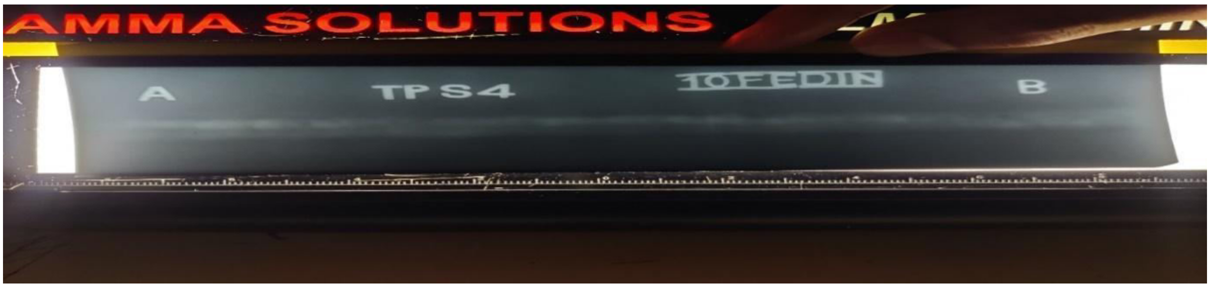

Fig 4.13 radiography test result of test sample 4.

A porosity of 0.2 mm is in identified on the test specimen 4. Which is in acceptable level.

Sample 5

Fig 4.14 radiography test result of test sample 5.

A porosity of 20mm is identified on test specimen 5. Which is in acceptable level.

Sample 6

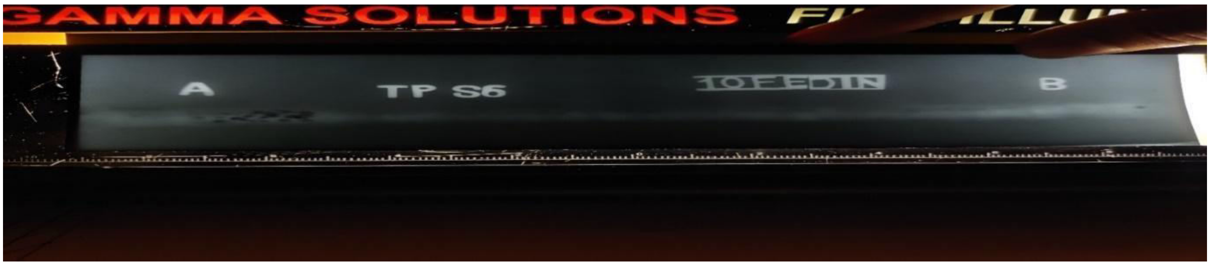

Fig 4.15 radiography test result of test sample 6.

A cluster porosity of 20 mm length is identified on test sample 6. Which should be rejected.

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4.5 Cause and Effect Diagram

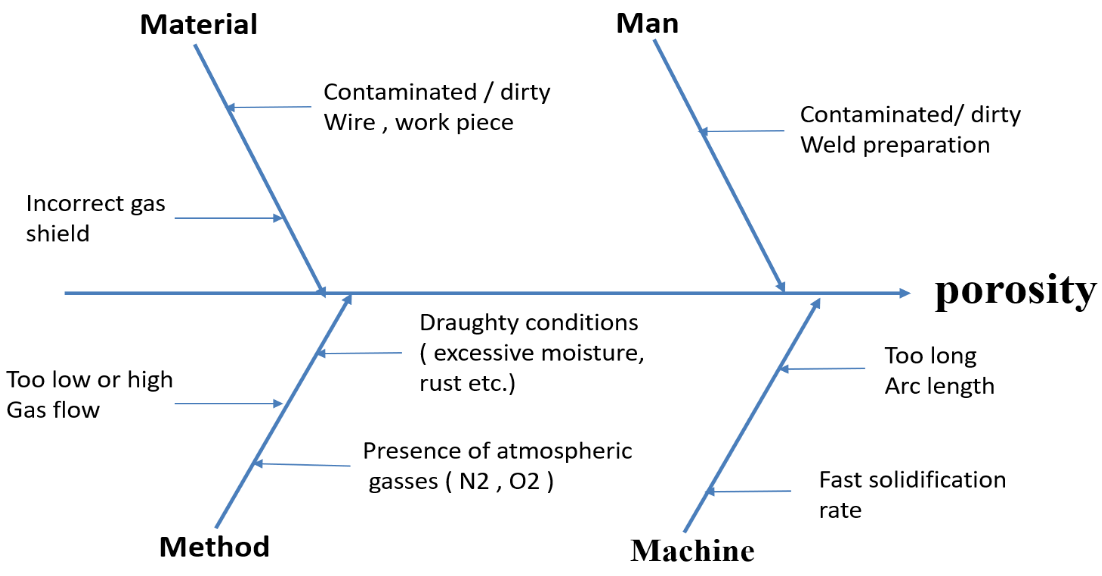

Fig 4.16 cause and effect diagram for porosity.

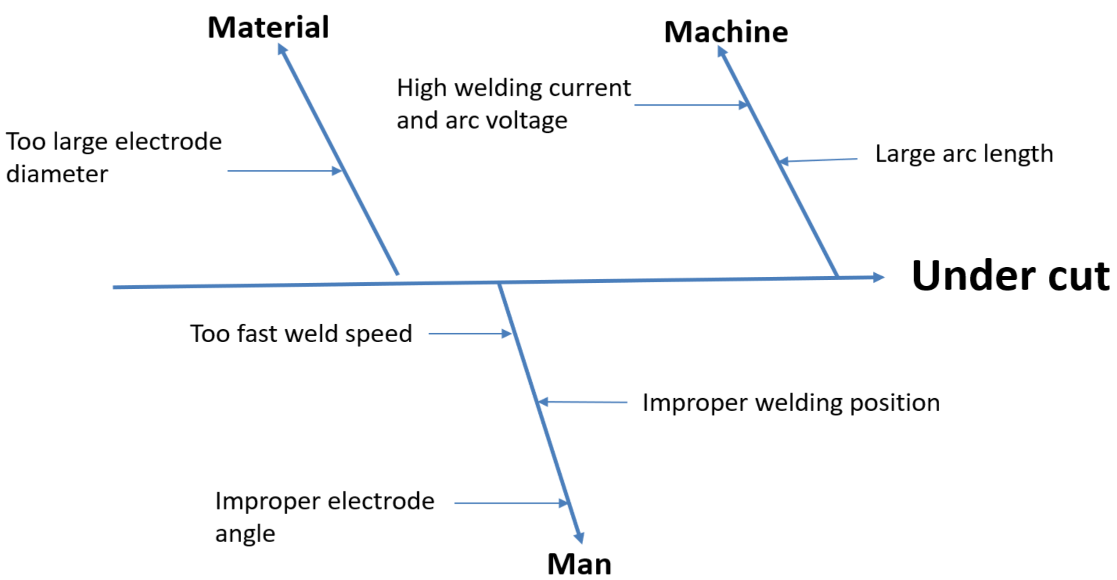

Fig 4.17 cause and effect diagram for under cut.

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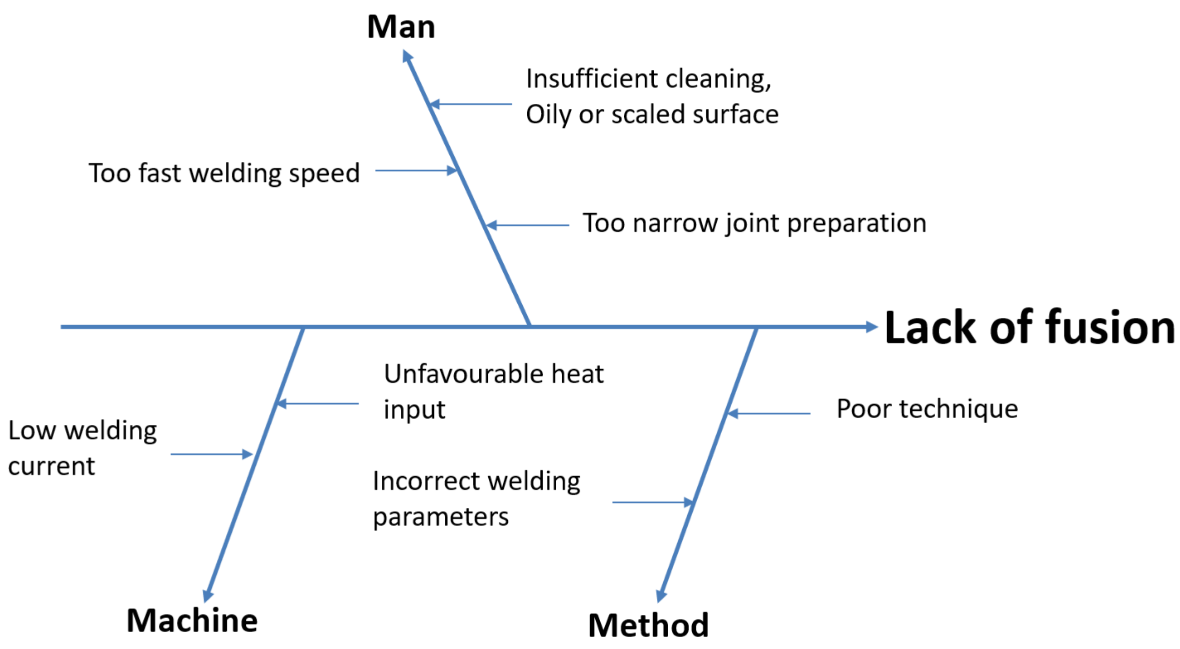

Fig 5.18 cause and effect diagram for lack of fusion.

V. CONCLUSION

In the field of welding, ensuring high-quality welds is significance to the structural integrity and longevity of the finished product. In this paper a case study on Tungsten Inert Gas (TIG) welding defects, employing a cause-and-effect diagram to analyse various issues such as porosity, lack of fusion, and undercutting. These defects are categorized based on potential sources: man, machine, material, and method. Porosity, a common defect, can result from gas entrapment during the welding process. Lack of fusion occurs when there is insufficient bonding between the base metals and the filler material. Undercutting refers to the excessive melting of the base metal near the weld, creating a groove. Identifying the root causes of these defects is essential for improving welding quality. Factors such as improper technique, equipment malfunctions, low quality materials, or flawed welding methods can all contribute to defect formation. By pinpointing these root causes, corrective measures can be implemented to enhance welding processes and reduce the occurrence of defects. Sample 2, highlighted in the study, serves as a benchmark for defect-free welding. It exhibits exemplary characteristics in non-destructive testing, with a gas flow of 13 L/min and welding current of 85 A. However, it's noted that not all defects can be detected using a single non-destructive testing method. Ultrasonic testing emerges as a preferred method due to its higher sensitivity compared to other non-destructive testing techniques. Its ability to detect minute flaws within the weld ensures a thorough assessment of weld integrity, contributing to the overall quality improvement efforts. In summary, the study underscores the multifaceted nature of TIG welding defects and the importance of identifying their root causes for quality enhancement. It emphasizes the necessity of employing a combination of testing methods and highlights the efficacy of ultrasonic testing in achieving comprehensive defect detection.

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