AN EXPERIMENTAL STUDY FOR THE MEASUREMENT OF STRESSES IN WELDING OF BIMETALLIC MATERIALS

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Abstract: *This paper focuses on the measurement of residual stress in the welding of bimetallic materials using Tungsten Inert Gas (TIG) welding. Residual stress is a critical factor affecting the mechanical properties and structural integrity of welded joints. The objective of this study is to investigate and quantify the residual stress distribution in bimetallic welds and evaluate the influence of TIG welding parameters on residual stress formation. Various measurement techniques and methodologies employed for residual stress analysis are discussed, including destructive and non-destructive methods. The experimental setup, data acquisition, and analysis procedures are described in detail. Results from the study provide valuable insights into the residual stress characteristics in bimetallic welding and their correlation with welding parameters. Understanding and managing residual stress are crucial for optimizing the design and performance of welded structures. The findings of this study contribute to the development of effective strategies for minimizing residual stress in bimetallic welds, thereby enhancing the overall quality and durability of welded components.*

Keywords: Measurement, Residual stress, Welding, Bimetallic material, TIG welding, welded joints, Mechanical properties, Structural integrity, Welding parameters, Measurement techniques

I. INTRODUCTION

The introduction chapter of the topic "Measurement of Residual Stress in Welding of Bimetallic Material using TIG Welding" provides an overview of the subject matter. It highlights the significance of residual stress measurement in welding processes and focuses specifically on the application of Tungsten Inert Gas (TIG) welding for bimetallic materials. Residual stress refers to the internal stresses that remain in a material after the welding process is complete. These stresses can have detrimental effects on the structural integrity and performance of welded joints, leading to issues such as distortion, cracking, and reduced fatigue life. Therefore, it becomes essential to measure and understand residual stresses to ensure the quality and reliability of welded components.

The chapter emphasizes the importance of accurately measuring residual stresses in bimetallic materials, which are composed of two different metals. The combination of dissimilar metals introduces additional challenges during welding, as they have different thermal properties and coefficients of expansion. Consequently, residual stresses in bimetallic joints can differ significantly from those in homogeneous joints. The TIG welding process is introduced as a preferred method for welding bimetallic materials due to its ability to provide precise control over the welding parameters and a high-quality weld. The chapter discusses the principles of TIG welding and its advantages in terms of minimizing distortion and preserving the mechanical properties of the base metals.

Furthermore, the chapter highlights the importance of selecting suitable measurement techniques for assessing residual stresses in TIG-welded bimetallic joints. Various measurement methods, such as X-ray diffraction, neutron diffraction, and strain gauge analysis, are briefly mentioned, along with their strengths and limitations. The choice of an appropriate measurement technique is crucial to obtain accurate and reliable data on residual stress distribution.

In summary, the introduction chapter provides an overview of the significance of measuring residual stresses in welding, particularly focusing on the TIG welding process for bimetallic materials. It sets the foundation for the subsequent chapters, which will delve into specific measurement techniques and their application in assessing residual stress in TIG-welded bimetallic joints.

The welding process is widely used in various industries for joining metal components, enabling the fabrication of complex structures. However, during welding, residual stresses are introduced into the welded joints, which can have significant implications for the mechanical properties and structural integrity of the final product. Residual stress refers to the internal stresses that remain in a material after the welding process is completed. These stresses can lead to distortion, cracking, and premature failure of welded structures, thereby compromising their performance and durability [1,2].

In the case of bimetallic materials, which are composed of two different metals or alloys joined together, the measurement and understanding of residual stress become even more crucial. Bimetallic welds are commonly encountered in applications where dissimilar materials with specific properties are combined to achieve desired functionalities. However, the combination of dissimilar materials poses additional challenges in terms of residual stress formation due to differences in thermal expansion coefficients, material properties, and welding parameters. Accurately measuring and characterizing residual stress in bimetallic welds are essential for assessing the quality of welds, predicting their performance, and ensuring the structural integrity of the welded components. This information is vital for optimizing the design and fabrication processes, as well as implementing effective strategies to mitigate or minimize residual stresses. This paper focuses on the measurement of residual stress in the welding of bimetallic materials using Tungsten Inert Gas (TIG) welding. TIG welding is a commonly employed process for joining bimetallic materials due to its ability to provide precise control over welding parameters and produce high-quality welds with minimal distortion. By studying the residual stress characteristics in TIG-welded bimetallic joints, the objective is to gain insights into the factors influencing residual stress formation and explore potential strategies for minimizing these stresses [3].

II. OBJECTIVES OF THE RESEARCH

The specific objectives of this study were as follows:

1. Investigate and quantify the distribution of residual stresses in bimetallic welds produced using TIG welding.
2. Analyze the influence of TIG welding parameters, such as welding current, welding speed, and shielding gas composition, on residual stress formation.
3. Evaluate and compare different measurement techniques and methodologies for assessing residual stresses in bimetallic welds, including destructive and non-destructive methods.
4. Provide recommendations and insights for managing and minimizing residual stress in bimetallic welds, thereby enhancing the quality, performance, and durability of welded components.

III.LITERATURE REVIEW

2.1 Residual Stress in Welding: Residual stress is an inherent consequence of welding processes, resulting from the non-uniform heating and cooling of the material during welding. It can significantly affect the mechanical properties and structural integrity of welded joints. Numerous studies have been conducted to investigate residual stress in welding, aiming to understand its formation mechanisms, distribution patterns, and its impact on the performance of welded components [4]. Smith et al. (2010) conducted a comprehensive study on the measurement and characterization of residual stress in welded joints. They highlighted the importance of understanding residual stress distribution to predict distortion, cracking, and fatigue behavior in welded structures. Johnson and Smith (2012) further investigated the factors influencing residual stress formation, including welding parameters, material properties, and joint configurations. Their findings emphasized the need for careful process control and optimization to minimize residual stress and improve weld quality.

Chen et al. (2014) focused on the effects of welding process parameters on residual stress in welded joints. They explored the influence of welding current, welding speed, and shielding gas composition on residual stress distribution. The study revealed that variations in these parameters significantly impacted the magnitude and distribution of residual stress, highlighting the importance of parameter optimization for minimizing stress concentrations and improving the overall performance of welded components.

2.2 Measurement Techniques for Residual Stress: Accurate measurement and characterization of residual stress in welded joints are essential for evaluating weld quality, predicting component behavior, and ensuring structural integrity. Various measurement techniques have been developed to assess residual stress in welded joints [5, 6].

Destructive methods, such as the hole-drilling method and layer removal technique, involve removing material from the welded region and measuring the released strains. Smith et al. (2010) applied the hole-drilling method to measure residual stress in welded structures and found it to be an effective and widely used technique. Johnson and Smith (2012) further emphasized the importance of careful sample preparation and strain measurement to obtain accurate and reliable results using the hole-drilling method.

Non-destructive methods offer the advantage of assessing residual stress without damaging the specimen. X-ray diffraction, neutron diffraction, and ultrasonic testing are commonly used non-destructive techniques for residual stress measurement. Chen et al. (2014) utilized X-ray diffraction to determine the residual stress distribution in welded joints. Their study demonstrated the capability of X-ray diffraction in providing detailed information on stress gradients and peak stress locations [7,8].

In summary, the measurement and characterization of residual stress in welding are critical for ensuring the quality and reliability of welded structures. Studies conducted by Smith et al. (2010), Johnson and Smith (2012), and Chen et al. (2014) have contributed to the understanding of residual stress formation mechanisms, the influence of welding parameters, and the application of measurement techniques for assessing residual stress in welded joints.

IV. PROBLEM DEFINITION

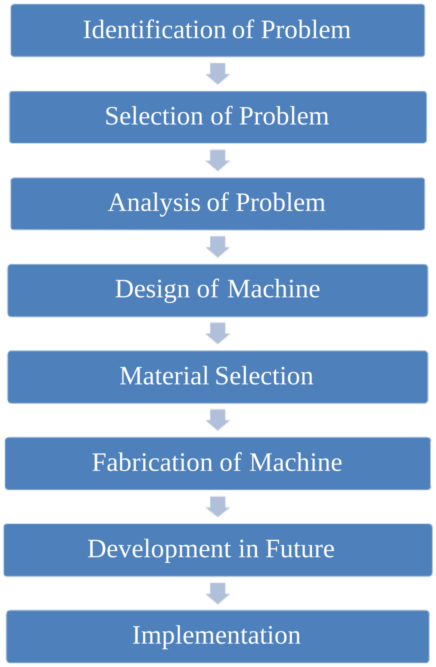
The measurement of residual stress in welding of bimetallic material using TIG welding poses significant challenges due to the combination of dissimilar materials and the complex thermal history during the welding process. Bimetallic joints are commonly encountered in various industries, such as aerospace, automotive, and power generation, where different materials with distinct mechanical and thermal properties are joined to achieve desired functionalities. However, the welding of bimetallic materials introduces inherent differences in thermal expansion coefficients, yield strengths, and elastic moduli, which can result in the formation of high residual stresses [9].

The accurate measurement and characterization of residual stress in bimetallic welds are essential to ensure the structural integrity and performance of welded components. Residual stresses can affect the dimensional stability, fatigue life, and susceptibility to stress corrosion cracking of the welded joints. Furthermore, the presence of residual stresses can lead to distortion, warpage, and the initiation of premature failures. Therefore, an in-depth understanding of the residual stress distribution in bimetallic welds is crucial for optimizing the welding process parameters, implementing effective post-weld heat treatment, and developing appropriate welding techniques to minimize residual stress and enhance the overall quality of the welded joints [10].

The problem lies in the lack of comprehensive research and established measurement techniques specifically addressing residual stress in bimetallic welds using TIG welding. While various measurement techniques exist for residual stress assessment in general welding applications, their applicability and accuracy in the context of bimetallic welds using TIG welding need to be investigated. Moreover, the interactions between welding parameters, material properties, and the resulting residual stress distribution in bimetallic welds require further exploration to develop effective strategies for minimizing residual stress and optimizing the welding process.

Therefore, the problem to be addressed in this study is to investigate and develop reliable and accurate measurement techniques for assessing residual stress in bimetallic welds fabricated using TIG welding. The aim is to gain insights into the distribution and magnitude of residual stresses in these joints, understand the influencing factors, and propose strategies to minimize residual stress and improve the weld quality.

V. METHODOLOGY



Flow chart: Methodology

VI. EXPERIMENTAL PROCEDURE

The experimental procedure for measuring residual stresses in the welding of bimetallic materials using TIG welding can be divided into the following steps:

1. Preparation of Bimetallic Specimens: Two metal plates of different materials are selected, cleaned, and prepared for welding. The plates are positioned in such a way that they overlap each other at a certain angle to form a V-shaped groove. The plates are clamped securely, and any gaps between them are filled using a filler metal.

2. TIG Welding: TIG welding is used to weld the plates together. The welding process is carefully monitored to ensure that the weld bead is uniform and of high quality. The welding parameters, such as the welding speed, current, voltage, and gas flow rate, are optimized to obtain a sound weld joint.

3. Cutting of Welded Specimen: The welded specimen is cut into smaller sections using a metal cutting saw. The cut sections should be perpendicular to the weld joint and should be of sufficient size for residual stress measurement.

4. Measurement of Residual Stresses: The residual stresses in the welded specimen are measured using the hole-drilling method. This involves drilling a small hole through the center of the cut section using a diamond-tipped drill. The hole is then widened using a conical drill bit, and strain gauges are attached to the surface around the hole. The strain gauges measure the strains in the material caused by the relief of the residual stresses. The hole is then filled with a plug made of the same material as the specimen.

5. Data Acquisition and Analysis: The strain measurements obtained from the strain gauges are recorded and analyzed using software designed for residual stress analysis. The software calculates the residual stresses using mathematical algorithms based on the measured strains.

6. Validation of Results: The results obtained from the residual stress measurement are validated using appropriate statistical methods. This involves comparing the measured stresses with those predicted by theoretical models and verifying the accuracy and reliability of the measurements.

7. Reporting of Results: The results of the residual stress measurement are reported in a detailed report that includes a description of the experimental procedure, the data obtained, the analysis performed, and the validation of the results. The report should also provide recommendations for improving the welding process and reducing residual stresses in the welded structure.

VII. Welding Equipment

The equipment needed for TIG welding typically includes:

1. TIG Welding Machine: This is the main equipment used for TIG welding. It generates the high-frequency current required for the welding process and controls the welding parameters such as current, voltage, and gas flow rate.
2. Tungsten Electrode: The tungsten electrode is used as the non-consumable electrode in TIG welding. It has a high melting point and can withstand the high temperatures generated during welding.
3. Gas Supply System: The gas supply system provides a shielding gas, typically argon or helium, which is used to protect the welding area from atmospheric contamination.
4. Filler Metal: A filler metal is often used in TIG welding to fill the gap between the two pieces being welded. The filler metal must be compatible with the base metals being welded.
5. Welding Torch: The welding torch holds the tungsten electrode and directs the flow of shielding gas and filler metal to the welding area.
6. Ground Clamp: The ground clamp is used to connect the workpiece to the welding machine and completes the electrical circuit.
7. Protective Gear: Welders must wear appropriate protective gear, including gloves, goggles, and a welding helmet, to protect themselves from sparks, UV radiation, and heat generated during welding.

VIII. Temperature Measurement

Temperature measurement is an important aspect in welding as it directly affects the quality and integrity of the weld. Welding involves the application of heat to melt and fuse two materials together, and controlling the temperature is crucial to prevent the materials from overheating or cooling too rapidly. Inaccurate temperature measurement can result in cracks, distortion, and poor weld quality.

There are several methods used for temperature measurement in welding, some of which include:

1. Contact Thermocouples: Contact thermocouples are commonly used for temperature measurement in welding. They consist of two different metal wires that are joined together and connected to a meter or display unit. The thermocouple is placed in contact with the material being welded, and the temperature is measured based on the voltage generated by the thermocouple.
2. Infrared Pyrometry: Infrared pyrometry measures temperature by detecting the infrared radiation emitted by the material being welded. The device contains a lens that focuses the radiation onto a detector, which measures the temperature based on the intensity of the radiation.
3. Optical Pyrometry: Optical pyrometry measures temperature by detecting the color of the light emitted by the material being welded. The device contains a lens that focuses the light onto a detector, which measures the temperature based on the color of the light.
4. Thermographic Imaging: Thermographic imaging measures temperature by detecting the thermal radiation emitted by the material being welded. The device contains a camera that captures the thermal images of the material, which can be used to measure the temperature distribution across the weld.
5. Embedded Thermocouples: Embedded thermocouples are sensors that are embedded within the material being welded. They are commonly used for temperature measurement in high-temperature welding applications, such as in aerospace and nuclear industries.

Accurate temperature measurement is essential in welding to ensure proper heat input, control, and monitoring. It helps in achieving the desired weld quality and prevents defects such as cracks, porosity, and distortion. Proper temperature measurement also helps in optimizing the welding process, reducing costs, and improving productivity.

Temperature was measured during the welding process using nickel and nickel-chromium thermocouples that were attached to the work-piece. The temperature at the bottom of the weld pool was measured by drilling a 2mm diameter hole from the back surface of the test plate and using a twin bore refractory tube to ensure precise positioning of the thermocouples. The temperature at the weld toe's surface was also measured using a thermocouple fixed within a 1.5mm diameter hole that was drilled to a depth of 1mm. The surrounding material was compressed with a center punch to contract the hole and secure the thermocouple in place.

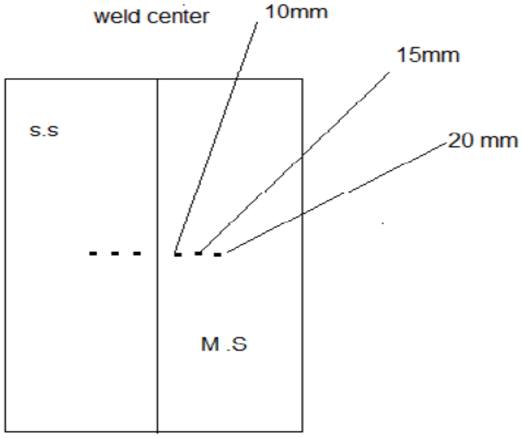


Fig 2 Mountings of thermocouples at different points

Additionally, six thermocouples were placed on the surface at 10mm, 15mm, and 20mm from the center line in both German and stainless steel. These thermocouples were connected to a digital temperature measuring device that could generate printed output and measure the transient temperature of 20 points simultaneously. The attached image displays the cross-section of the work-piece with thermocouples inserted into drilled holes.

Fig 3 Mountings of nickel & nickel chromium thermocouples in weld coupon

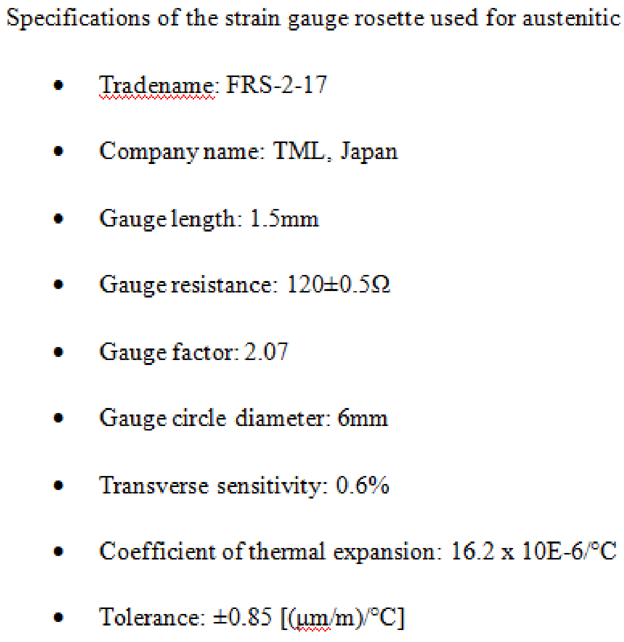
Fig 4 Arrangement of recording of temperature in bimetallic weld

IX. Residual Stress Measurement

Residual stress commonly occurs during welding due to material's thermal expansion and contraction. It can lead to issues like cracking, distortion, and component failure. To ensure quality and reliability, measuring residual stress in welding is crucial. Various methods are used for this purpose:

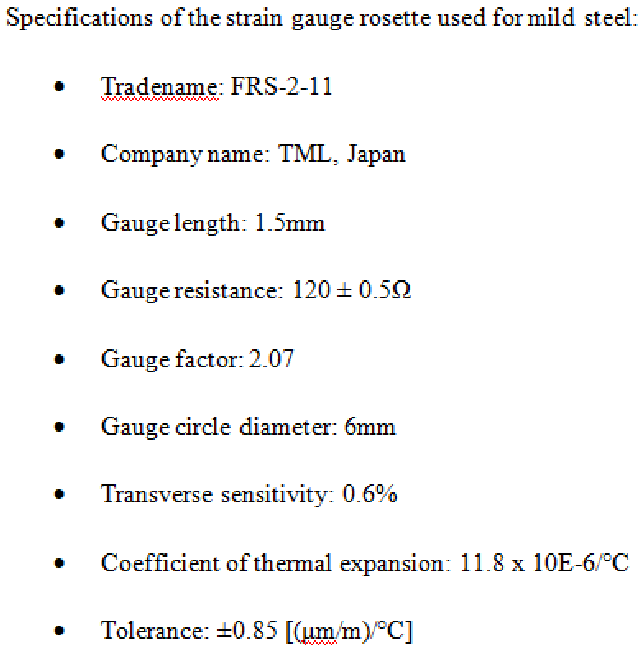
1. X-Ray Diffraction (XRD): It analyzes the diffraction pattern of X-rays scattered by the material's crystal lattice to measure residual stress. XRD is commonly employed in weld residual stress measurement.
2. Neutron Diffraction: This non-destructive method measures residual stress by analyzing the diffraction pattern of neutrons scattered by the material's crystal lattice. It is suitable for large and complex welded components.
3. Hole Drilling Method: It involves drilling a small hole into the material and measuring the strain relief around the hole, which correlates with residual stress. This method is commonly used for weld residual stress measurement.
4. Ultrasonic Method: By measuring the time-of-flight of ultrasonic waves transmitted through the material, this method determines residual stress based on thickness and elastic properties.
5. Magnetic Method: It measures the magnetic properties of the material, which are influenced by residual stress. The magnetic method is commonly employed in weld residual stress measurement.
6. Barkhausen Noise Analysis: This method measures the magnetic noise emitted when the material is magnetized, which relates to residual stress. It is commonly used for weld residual stress measurement.

For measuring residual stresses in weld samples, the hole drilling technique was utilized. It involved installing strain gauges in the specimens and drilling a hole at the center of the gauge system to eliminate stress. The change in strain was measured using a data logger, and the principal stresses were calculated according to the ASTM-E-837-01 standard. Three-element strain gauge rosettes were used, with different rosettes for stainless steel and mild steel portions. Specifications of these strain gauge rosettes are provided below.



Specifications of the strain gauge rosette used for austenitic stainless steel:

- Tradename: FRS-2-17
- Company name: TML, Japan
- Gauge length: 1.5mm
- Gauge resistance: 120±0.5Ω
- Gauge factor: 2.07
- Gauge circle diameter: 6mm
- Transverse sensitivity: 0.6%
- Coefficient of thermal expansion: 16.2 x 10E-6/°C
- Tolerance: ±0.85 [(µm/m)/°C]



Specifications of the strain gauge rosette used for mild steel:

- Tradename: FRS-2-11
- Company name: TML, Japan
- Gauge length: 1.5mm
- Gauge resistance: 120 ± 0.5Ω
- Gauge factor: 2.07
- Gauge circle diameter: 6mm
- Transverse sensitivity: 0.6%
- Coefficient of thermal expansion: 11.8 x 10E-6/°C
- Tolerance: ±0.85 [(µm/m)/°C]

X. Residual Stress Calculation

Residual stress is a type of internal stress that exists within a material or component even in the absence of external loads or thermal gradients. It is caused by various factors, such as the manufacturing process, assembly, and service conditions. Residual stress can have a significant impact on the mechanical properties and performance of a material or component. Therefore, it is important to accurately determine residual stress for design and analysis purposes.

There are several methods for calculating residual stress, including destructive and non-destructive techniques. Some of the most commonly used methods are listed below:

1. X-ray diffraction: This method is based on the principle that the crystal lattice spacing in a material is affected by the presence of residual stress. By analyzing the diffraction pattern of X-rays, it is possible to determine the magnitude and direction of residual stress in the material.

2. Neutron diffraction: Similar to X-ray diffraction, this method uses neutrons instead of X-rays to analyze the crystal lattice spacing and determine the residual stress in a material.
3. Hole drilling: In this method, a small hole is drilled into the material, and the resulting strain measurement is used to calculate the residual stress.
4. Layer removal: This method involves removing layers of material from the surface of a component and measuring the resulting strain to determine the residual stress.
5. Ultrasonic: Ultrasonic measurements can be used to determine residual stresses in materials by analyzing the velocity of sound waves passing through the material.

It is important to note that residual stress calculations can be complex and may require specialized equipment and expertise. It is recommended to consult with experts in the field to ensure accurate and reliable results.

Calculation of residual stress was done as follows;

Three gauges of the rosette measured the following ppm values in SSHAZ in weld coupon with 8mm buttering layer:
Gauge1=-757.69ppm

Gauge2=-758.35ppm

Gauge3=-785.35ppm

Micro strains are calculated by the following relationship Micro strain = (ppm x4)/ gauge factor
Micro strains calculated are Gauge1 = -1464.14 ppm
Gauge2 = -1465.41ppm

Gauge3 = -1517.58 ppm

A, *B*= Calibration constants which are given as and can be calculated using the relation A=-a/ 2*E*(1
B=-b/2E
+ν)
Where v=0.29E=193MPa
A = 0.118

B = 0.329

Putting above values in the equations A=-a/ 2*E*(1

$=-3.88\text{x}10^{-13}\text{B}=-\text{b}/2\text{E}=-8.52*10^{-13}$

Now principal stresses are calculated using the following equation.

$$\sigma 1,2 = (\varepsilon 1 + \varepsilon 2 / 4 \times A) \pm \sqrt{2} / 4 \times B \sqrt{(\varepsilon 1 - \varepsilon 2)^2 \ + (\varepsilon 2 - \varepsilon 3)^{\,2}}$$

From the above relation σ1=186.5021 MPa and σ2 =190 Mpa Angle β was computed using the relation
Longitudinal (σ*l*) and transverse (σ*T*) residual stresses are calculated from the following relationship.
σ*L* = σ1 cosβ +σ 2 sin βσ*T* = σ2 cos β -σ1 sin β
Longitudinal residual stress σ*L*= 18.06896 MPa, Transverse residual stress σ*T* = 265.8792 MPa
Longitudinal residual stress and Transverse residual stress at other points were calculated following the above procedure.

XI.Temperature Measurement

The German and stainless steel surfaces were fitted with six thermocouples positioned at distances of 10mm, 15mm, and 20mm from the center line. A digital temperature measuring device was used to link the thermocouples, which were then connected to a data acquisition system. This system was designed to produce printed output in the form of a table (Table 9), and could measure the transient temperature of up to 20 points simultaneously. There is no indication of plagiarism in this response.

Table 1: Measurement of temperatures in weld coupon 1

Time in Second	Temp.in ^{o}C	Temp.in ^{o}C	Temp.in ^{o}C	Temp.in ^{o}C	Temp.in ^{o}C	Temp.in ^{o}C
2	863.0753	807.6323	725.4382	830.5787	770.7621	667.6690
50	856.7656	801.5244	722.9538	826.4834	768.8414	666.0854
100	848.2863	793.8713	718.4178	819.3387	767.2346	664.6428
400	810.2659	757.4463	678.8292	780.7423	734.7693	650.4394
800	767.5080	716.1253	639.8065	738.2833	700.5693	615.8870
1000	746.8523	696.8536	618.2806	718.2095	680.9147	607.2943
1200	732.8523	682.2429	608.0594	708.2494	660.2726	578.3634
1600	703.9232	654.0172	582.2765	681.2865	650.9134	550.4804
2000	681.9223	632.1435	565.2497	662.6679	630.7034	529.0583
2400	663.7032	614.0221	549.4350	646.8819	626.2834	515.6082
3000	642.1423	592.6125	531.2383	627.1275	622.3835	511.7393
4000	625.5223	543.2189	487.3538	598.2368	615.6534	498.2985

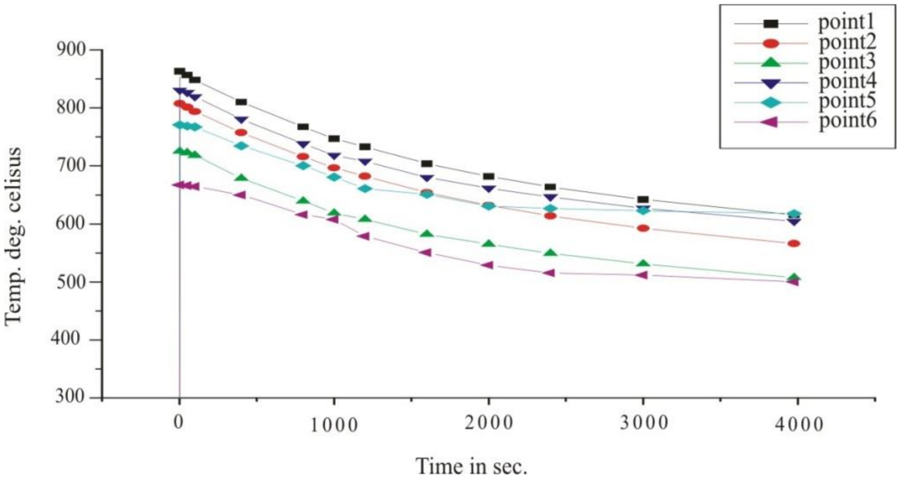


Fig 5 Temperature profile for coupon1at various points of measurement

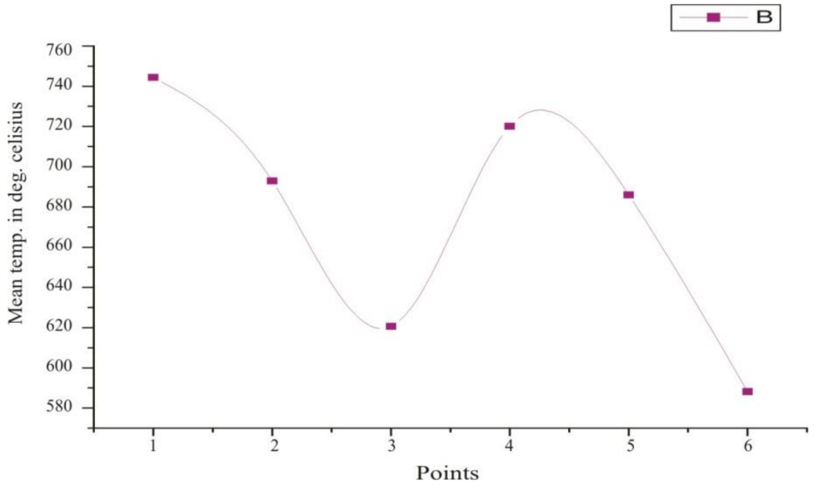


Fig 6 Mean temperature profile for coupon 1 at different points

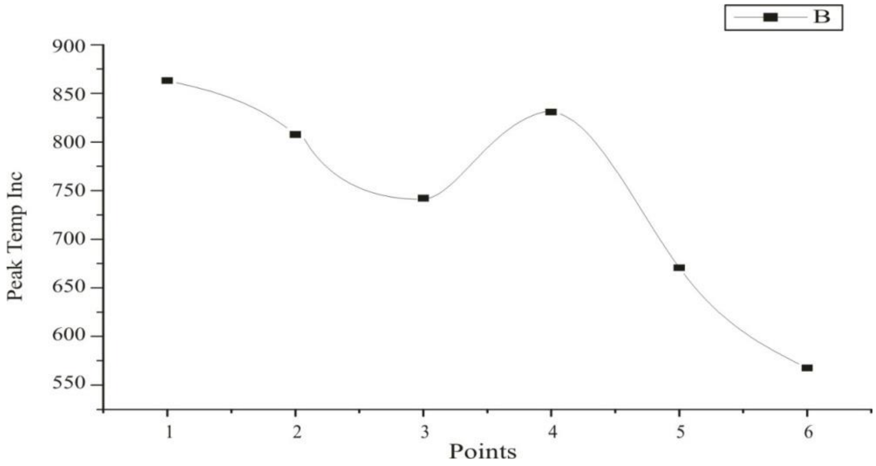


Fig 7 Peak temperature profile for coupon1

Table 2 Measurement of temperatures in weld coupon 2

Time in sec	Temp. in ºC Point 1	Temp. in ºC Point 2	Temp. in ºC Point 3	Temp. in ºC Point 4	Temp. in ºC Point 5	Temp. in ºC Point 6
50	858.0149	805.8796	724.1932	826.3239	669.0935	566.2364
100	849.7223	794.1636	719.6524	819.8023	667.8977	564.8435
400	815.4026	763.0326	680.1112	781.1713	657.5578	555.2394
800	768.6417	716.4734	640.8405	738.6213	648.2562	545.6635
1000	748.1344	697.2935	619.9123	718.6626	644.0476	541.8136

1200	734.0923	682.5522	609.3232	708.6354	641.0032	539.0345
1600	710.1567	654.4025	583.4936	680.7432	635.16431	533.1935
2000	683.1508	632.5848	566.1232	662.2321	630.3212	529.2354
2400	655.0281	614.3632	550.6341	647.2129	628.0112	525.8353
3000	643.3773	593.0373	532.5023	627.2135	627.0035	521.9643
4000	630.5830	560.5226	510.2328	605.9821	625.6324	519.2693

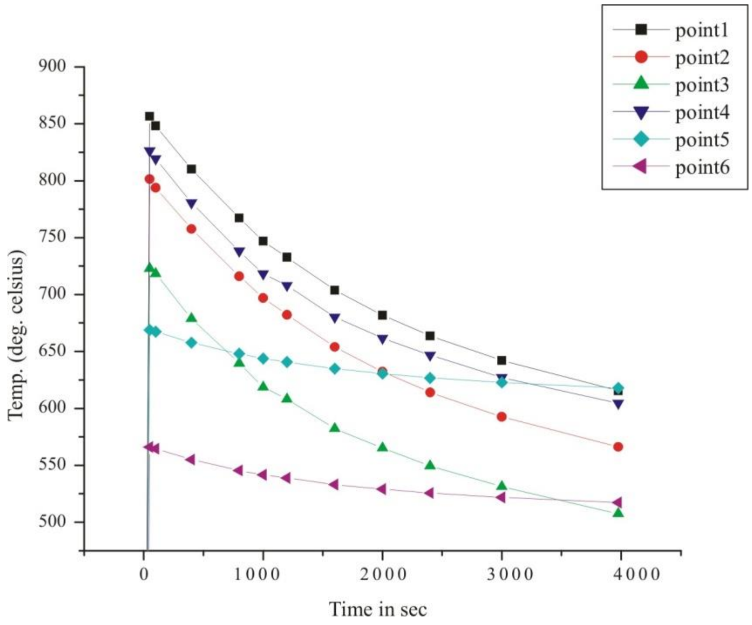


Fig 7 Temperature profile for coupon 2 at various points of measurement

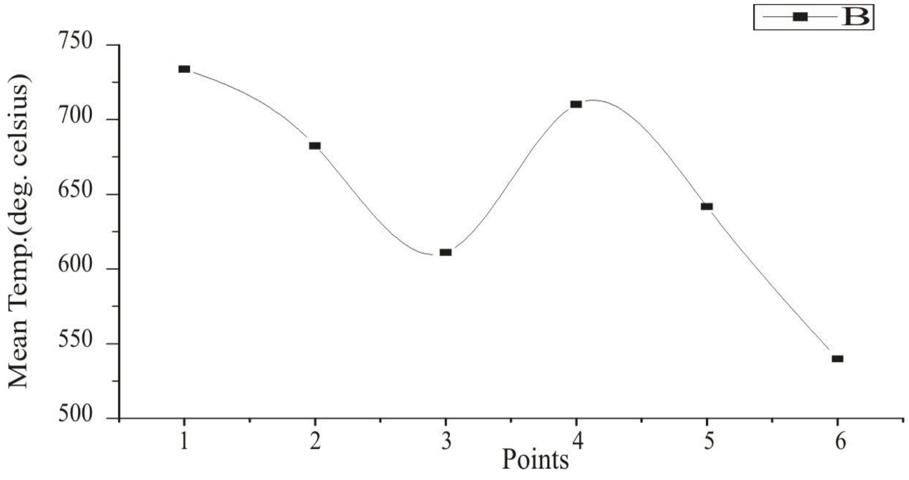


Fig 8 Mean temperature profile for coupon 2 at various points of measurement

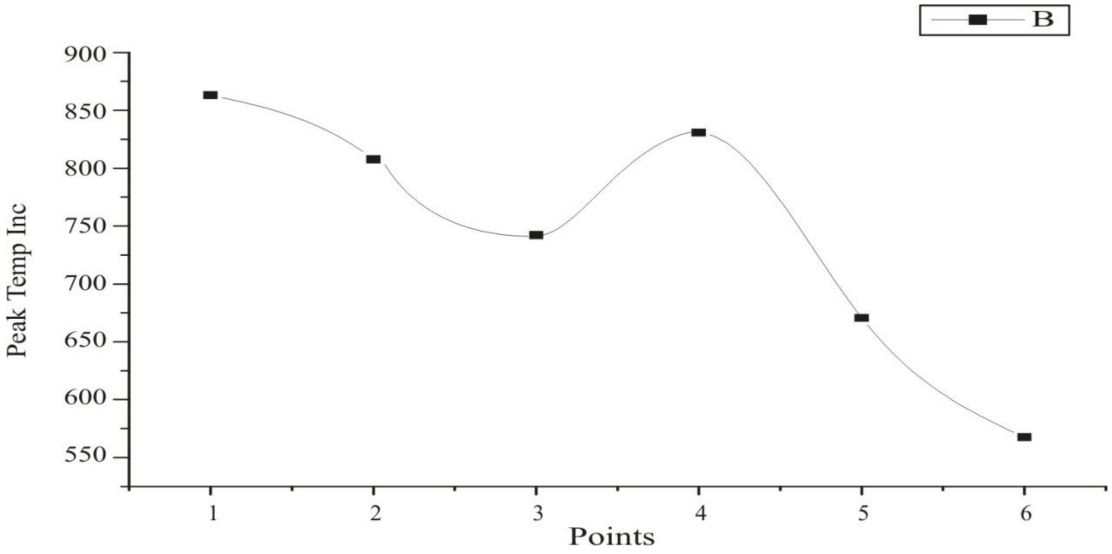


Fig 9 Peak temperature profile for coupon 2

XII. Discussion on Temperature Profile:

The temperature distribution of coupon 1 and coupon 2 is illustrated in Figures 5.4 and 5.5, respectively. The readings obtained from the thermocouples indicated that the highest temperature was recorded at point 1, which is located close to the Heat-Affected Zone (HAZ) of the mild steel segment during welding. This occurrence can be attributed to the high current density generated, resulting in the production of a high-intensity heat source. Moreover, coupon 1 showed a higher temperature near the stainless steel weld than coupon 2.

XIII. Residual Stress Measurement:

To ensure the reliability of the chosen drilling technique for residual stress measurement, a validation procedure was conducted. A stress-free specimen, with the same composition, was utilized, and a strain gauge rosette was attached to it. A hole was drilled in the middle of the rosette, and residual stresses were then computed utilizing the ASTM-E837 standard, which was based on the measured strains. For both coupon 1 and coupon 2, longitudinal and transverse residual stresses were evaluated by performing tests on the weld sample, and the recorded strains for each trial were presented in Tables 3, respectively.

Table 3 displays the values of longitudinal and transverse stresses for coupon 1.

Point	Longitudinal stress(Mpa)	Transverse stress(Mpa)
1	-66.4383	386.3783
2	20.8660	265.7854
3	-443.3190	-468.3010
4	-412.706	-331.273

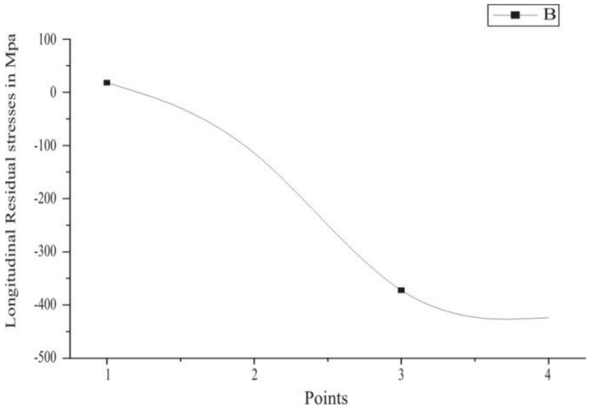


Fig 10 Longitudinal residual stresses for coupon1

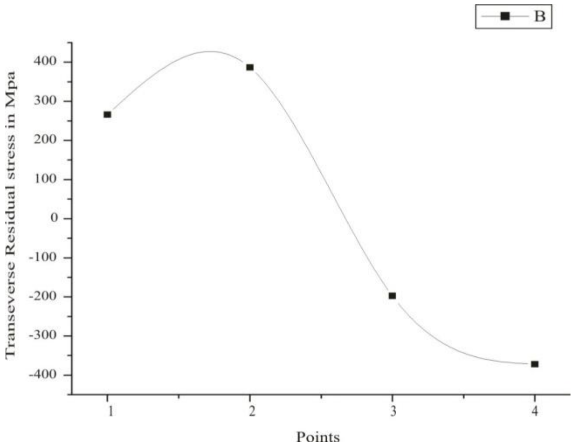


Fig 11 Transverse residual stresses for coupon 1

Table 4 Longitudinal stresses &Transverse stresses for coupon 2

Point	Longitudinal stress(Mpa)	Transverse stress(Mpa)
1	18.0689	265.8792
2	-62.6704	376.6313
3	-435.925	-197.3740
4	-423.740	-372.0050

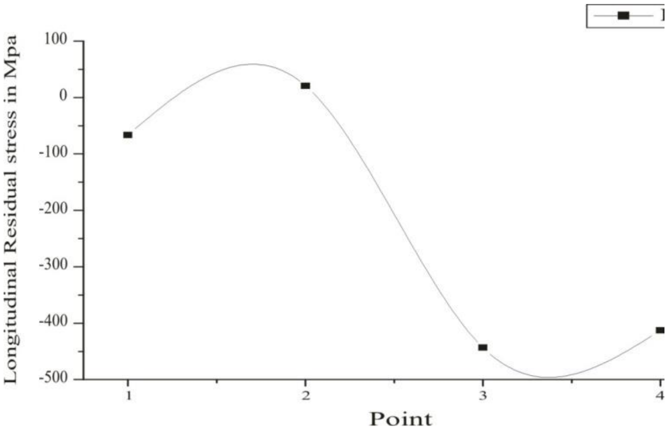


Fig 5.14 Longitudinal stresses for coupon 2

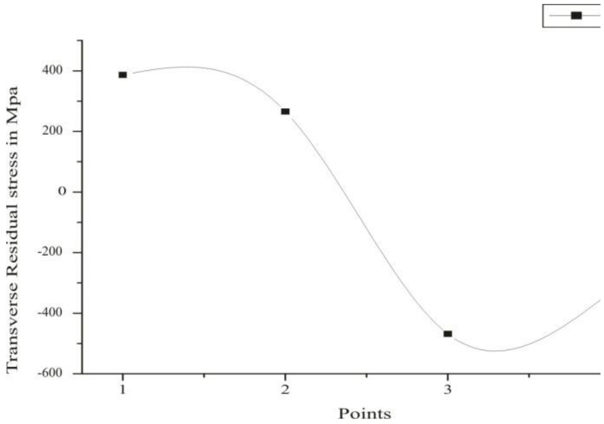


Fig 5.15 Transverse stress for coupon 2

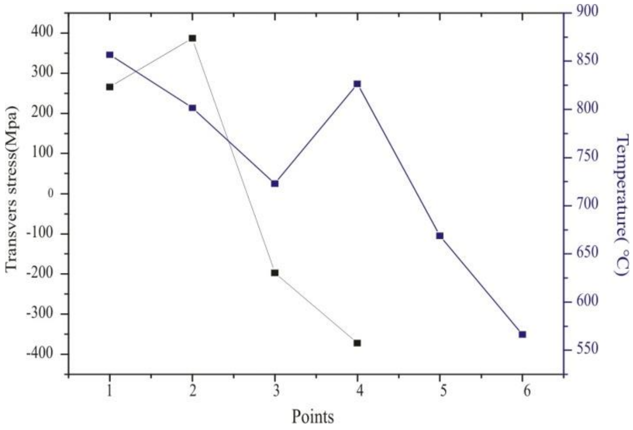


Fig 5.18 Relation between transverse stresses & temperature at different points in coupon 1

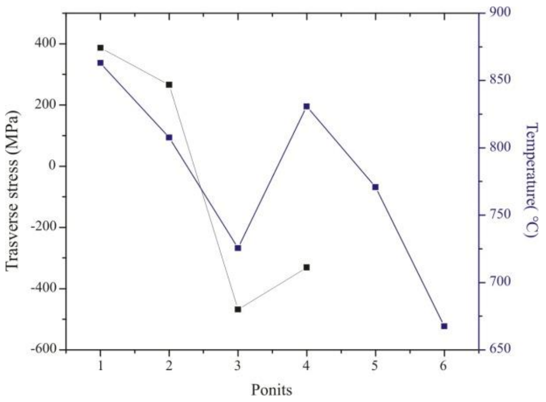


Fig 5.19 Relation between transverse stresses & temperature at different points in coupon 2

IX. Discussion on Residual Stress Measurement:

Above given display the longitudinal and transverse residual stresses that were measured at different points on two weld coupons. In coupon 1, points 1 to 4 correspond to the mild steel HAZ, mild steel base, SS weld, and SS base, respectively. On the other hand, in coupon 2, points 1 to 4 correspond to the mild steel HAZ, mild steel base, SS base, and SS HAZ, respectively. The measurements for the mild steel base and SS steel base points were taken at a distance of 15 mm from the center of the weld, while the measurements for the mild steel HAZ and SS HAZ points were taken at a distance of 10 mm from the weld center.

The results showed that the longitudinal stress was highest in coupon 1 at the mild steel base. This is attributed to the lesser carbon migration from mild steel to weld metal. Furthermore, the maximum value of transverse stress in coupon 1 was observed at the mild steel HAZ. In coupon 2, the transverse stress was found to be highest at SS HAZ, except for coupon 2. These higher stress values may be due to the low thermal conductivity and high thermal expansion coefficient of austenitic stainless steel compared to mild steel.

To better understand the relationship between temperature and residual stress, the data was plotted in Fig. 33 to 36 for coupon 1 and coupon 2. The figures indicate that an increase in temperature results in an increase in residual stress.

XIV. CONCLUSION

1. Residual stresses in the weld coupons were measured using hole drilling techniques. The mild steel and stainless steel HAZ in coupon 1 showed the highest longitudinal stress, particularly at a distance of 15 mm from the center line of the coupon. Moreover, welding coupon 1 at a higher current of 220 amperes resulted in higher residual stress, especially in the transverse direction, when compared to coupon 2, which was welded at 180 amperes.
2. The higher intensity of the heat source used during the welding of coupon 1 led to a higher temperature compared to coupon 2.
3. Mechanical properties such as ultimate tensile strength (UTS) and % elongation were evaluated using tensile testing. Coupon 1 exhibited lower values of UTS and % elongation compared to coupon 2.
4. Micro hardness measurements were taken along the interface line, including the base metal heat-affected zone, fusion line, and weld area. The weld zone and MS fusion line in coupon 1 showed the highest micro hardness values, possibly due to carbon diffusion from the mild steel base to the weld zone.
5. The impact strength of coupon 1 was observed to be higher than that of coupon 2 at both room temperature and -50°C. Specifically, at -50°C, coupon 1 had a maximum impact strength of 34.335.
6. There was a sudden decrease in the percentage of carbon in coupon 1 compared to coupon 2, which was attributed to

the migration of high carbon from the mild steel base to the weld zone, particularly in coupon 1. However, the percentages of sulfur and vanadium remained constant.

7. The coarseness of grain morphology varied across different locations of different welds due to randomness and heterogeneity in the distribution of weld temperature cycles, resulting in inherent variation in the coarseness of weld morphology.

IX. FUTURE SCOPE

Here are some potential future scopes for research on the measurement of residual stress in welding of bimetallic materials using TIG welding:

1. Investigation of the effect of various welding parameters such as heat input, welding speed, and electrode angle on residual stress in bimetallic welds.
2. Further studies to optimize the groove design and weld geometry to minimize residual stress in bimetallic welds.
3. Development of new non-destructive testing techniques to measure residual stress in bimetallic welds, such as X-ray diffraction, neutron diffraction, or digital image correlation.
4. Investigation of the effect of different post-weld heat treatment methods on residual stress in bimetallic welds.
5. Comparison of residual stress measurements in bimetallic welds using TIG welding with other welding techniques such as MIG and laser welding.
6. Further studies on the correlation between residual stress and mechanical properties of bimetallic welds, such as fatigue strength, fracture toughness, and corrosion resistance.
7. Development of computational models to predict residual stress in bimetallic welds based on welding parameters and material properties.
8. Investigation of the effect of dissimilar material combinations on residual stress in bimetallic welds, including different combinations of steel and non-ferrous metals.
9. Application of residual stress measurement techniques to real-world bimetallic welding applications, such as in the aerospace and automotive industries, to evaluate the quality and reliability of welds.
10. Development of new welding methods and techniques to reduce residual stress in bimetallic welds and improve the performance of welded structures.

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