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Review on Preparation of WPS / PQR for cladding of Hastelloy C 276 on carbon steel (WCB)

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ABSTRACT

This abstract describes the process of preparing a welding procedure specification (WPS) and a procedure qualification record (PQR) for cladding Hastelloy C 276 on carbon steel (WCB). The cladding process involves overlaying a layer of Hastelloy C 276 on the WCB substrate to improve its corrosion resistance and other properties. The WPS is a document that outlines the specific welding parameters, such as current, voltage, and filler material, that should be used during the cladding process. The PQR is a record that documents the testing and results of the welding process, which is used to qualify the WPS. The preparation of the WPS and PQR involves selecting appropriate welding procedures, conducting welding trials, and performing various tests to ensure that the resulting cladded material meets the required standards and specifications. The successful preparation of a WPS and PQR for cladding Hastelloy C 276 on WCB can result in improved corrosion resistance, increased durability, and enhanced performance of the cladded material.

Keyword: - WPS / PQR, Preparation of WPS, PQR for cladding of Hastelloy C 276, carbon steel (WCB)

1. METHODOLOGY

After a comprehensive literature review, we have determined that it is essential to examine the multi-parameter multitrack GTAW deposition process. Our goal is to produce coatings that are free of defects and possess the desired tribo-corrosion and mechanical properties. To achieve this, we will conduct experimental investigations with parametric and statistical analyses. To prepare for the cladding process, we will follow a methodology consisting of various steps, including the preparation of WPS and PQR documents, and conducting welding inspections. By taking this approach, we hope to improve our understanding of the impact of process parameters and ultimately enhance the quality of GTAW claddings.

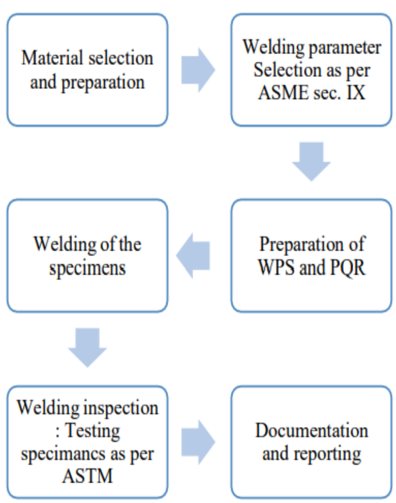


Fig-1: flow chart of methodology

1.1 Material selection and preparation

In any welding project, the selection and preparation of materials play a critical role, and this is no different for the cladding of Hastelloy C 276 on carbon steel (WCB). The project team had to carefully choose materials that were appropriate for the cladding process and prepare them accordingly to ensure efficient and effective welding.

Several factors were taken into consideration when selecting materials for the cladding process, including their properties, compatibility, and availability. In this case, carbon steel (WCB) was selected as the base metal due to its high strength and good weldability. Hastelloy C 276 was chosen as the cladding material due to its excellent corrosion resistance, high-temperature strength, and weldability. Compatibility between the materials was also a concern, and it was determined that carbon steel (WCB) and Hastelloy C 276 would metallurgically bond during the cladding process. These careful material selections and preparations were necessary to ensure the success of the cladding process.

Selection of base material

Based on the industry's requirements and the problem statement, we have opted for WCB grade carbon steel. WCB is a widely used grade of carbon steel for producing castings of valves, pumps, and various components in industries like oil and gas, chemical processing, and power generation. ASTM A216/A216M standard defines WCB as "cast carbon steel, grade B". Its carbon content usually ranges from 0.25% to 0.30%, and it contains other elements like silicon, manganese, and sulfur that contribute to its mechanical properties. The "B" designation indicates that this carbon steel grade has a minimum yield strength of 30,000 psi (or 205 MPa) and a minimum tensile strength of 70,000 psi (or 485 MPa).

Chemical composition (in %) of base material

Element	C	Mn	Si	P	S	Cr	Ni	Mo	Cu	V	CE	RE
Min	---	---	---	---	---	---	---	---	---	---	---	---
Max	0.250	1.000	0.600	0.035	0.035	0.500	0.500	0.200	0.300	0.030	0.430	1.000
Actual	**0.197**	**0.793**	**0.577**	**0.018**	**0.007**	**0.078**	**0.025**	**0.012**	**0.010**	**0.009**	**0.351**	**0.134**

Table 1 Chemical composition of base material

Selection of cladding material

Hastelloy C276 is a nickel-molybdenum-chromium alloy renowned for its exceptional resistance to corrosion in a diverse range of aggressive environments. It can withstand both oxidizing and reducing media, making it ideal for use in industries like chemical processing, petrochemical, and waste treatment.

The chemical composition of Hastelloy C276 primarily comprises nickel (Ni), followed by molybdenum (Mo), chromium (Cr), iron (Fe), and small amounts of other elements like tungsten (W) and cobalt (Co). This combination of elements provides the alloy with unparalleled resistance to corrosion and high-temperature oxidation.

Fig-2: Base material for cladding

Hastelloy C276 comes in several forms, including pipes, tubes, plates, sheets, and fittings, and can be utilized in a wide range of applications such as heat exchangers, reactors, and columns. It's straightforward to fabricate and weld, and it can be used in both oxidizing and reducing environments.

Hastelloy C276 is a preferred material for applications that require resistance to aggressive chemical environments, including sulfuric acid, hydrochloric acid, and acetic acid. It can also withstand chlorides, such as seawater, and high-temperature and high-pressure conditions.

Overall, Hastelloy C276 is a versatile and dependable material widely used in various industries due to its exceptional corrosion resistance properties and ability to endure harsh environments. The problem statement is to prepare WPS for the cladding of Hastelloy C276 on carbon steel grade WCB, which has been chosen due to the excellent anti-corrosive properties of Hastelloy C276.

1.2 Specifications

- HEAT # RL534
- Classification: ERNiCrMo-4.

Chemical analysis (%)													
C	Mn	Fe	P	S	Si	Cu	Ni	Co	Cr	Mo	V	W	Others
0.008	0.5	6.4	0.004	<0.001	0.04	0.03	57.5	0.1	15.6	15.9	<0.01	3.5	<0.50

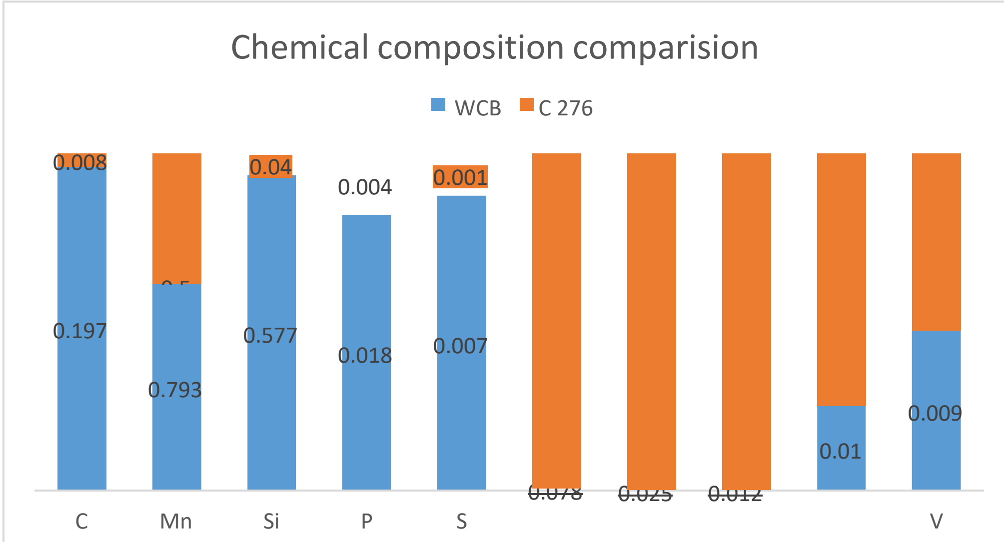


Table No. 2 Chemical analysis of cladding material (Hastelloy C 276)

2. Preparation of material

Several steps were involved in preparing the materials, including cleaning, surface preparation, and fit-up. To ensure the quality of the weld, it was necessary to remove any contaminants, and this was achieved through the cleaning process. The base metal was cleaned using a wire brush to remove rust or scale, while the cladding material was cleaned with a solvent to remove oil or grease.

Surface preparation involved grinding the base metal to create a smooth surface that would facilitate proper adherence of the cladding material. The cladding material was also ground to the appropriate thickness and width. Fit-up referred to the process of aligning the base metal and the cladding material to ensure a proper fit before welding.

To better understand the problem statement and facilitate further study, tokens were prepared in the form of a sleeve, and a coupon was created in the shape of a valve sleeve. Proper placement of the workpiece on the Auto TIG machine is depicted in Figure .

Coupon Size: O.D 168.97 X I.D 124.34 X 300 mm Long + 5.0 mm CRO (Machined)

Fig-3 Prepared token (valve sleeve) for cladding

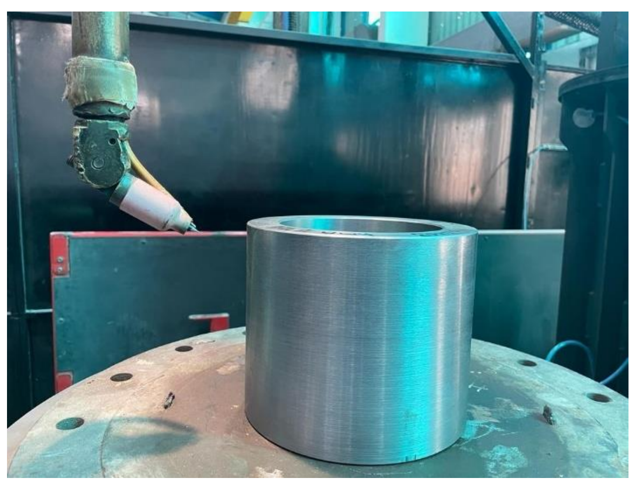


Fig-4: Workpiece on AT machine

2.1 Welding parameter setting

Optimizing welding parameters is a crucial step in the cladding process that ensures the weld's quality and integrity. This process involves identifying the optimal welding parameters, such as welding current, voltage, and travel speed, necessary to achieve the desired weld quality. This may require performing experiments to determine the optimal parameters.

The first step in optimizing welding parameters is identifying the relevant parameters for the welding process, including welding current, voltage, and travel speed, among others. These parameters depend on various factors, such as the material being welded, the joint design, and the welding process. It is vital to consider all these factors when selecting the welding parameters.

After identifying the relevant welding parameters, the next step is determining their optimal values. This involves conducting experiments to evaluate how changing the welding parameters affects the weld quality. Welding test specimens using different parameter combinations and assessing the weld quality through visual inspection, non-destructive testing, and destructive testing are part of the experiments.

The results of the experiments are analyzed to identify the optimal welding parameters for the welding process. The optimal parameters are the ones that produce welds of the desired quality and integrity. These parameters are then used to develop the welding procedure specification (WPS) that outlines the welding process for the specific application.

2.2 Preparation of WPS and PQR

The welding industry relies on two critical documents, the Welding Procedure Specification (WPS) and Procedure Qualification Record (PQR), to ensure safe and accurate welding operations.

A WPS is a written document that outlines welding procedures to ensure consistency and repeatability in the welding process. It covers information on welding materials, joint preparation, welding parameters (such as voltage, current, and travel speed), and any special instructions or precautions. A welding engineer or supervisor typically prepares the WPS, and welders use it as a guideline when performing welding operations.

On the other hand, a PQR is a record that documents the results of a Procedure Qualification Test (PQT) to verify the WPS's acceptability. The PQT involves welding a test coupon using the WPS under controlled conditions and subjecting the coupon to various mechanical tests and inspections to ensure that the weld meets the required quality standards. The PQR includes information on the welding process used, the test results, and any other relevant information.

The main objective of having a WPS and PQR in place is to ensure that welding operations are carried out in a consistent and controlled manner. By adhering to a qualified WPS, welders can produce high-quality welds that meet the requirements of the project specifications. This is especially crucial in industries such as aerospace, defence, and oil and gas, where weld quality and safety are paramount.

When creating a WPS and PQR, it is crucial to consider various factors such as the welding process, the material being welded, joint design and preparation, and welding position. The WPS should be based on a thorough understanding of the welding process and materials being used and should be developed in compliance with industry standards and guidelines, such as those set by the American Welding Society (AWS).

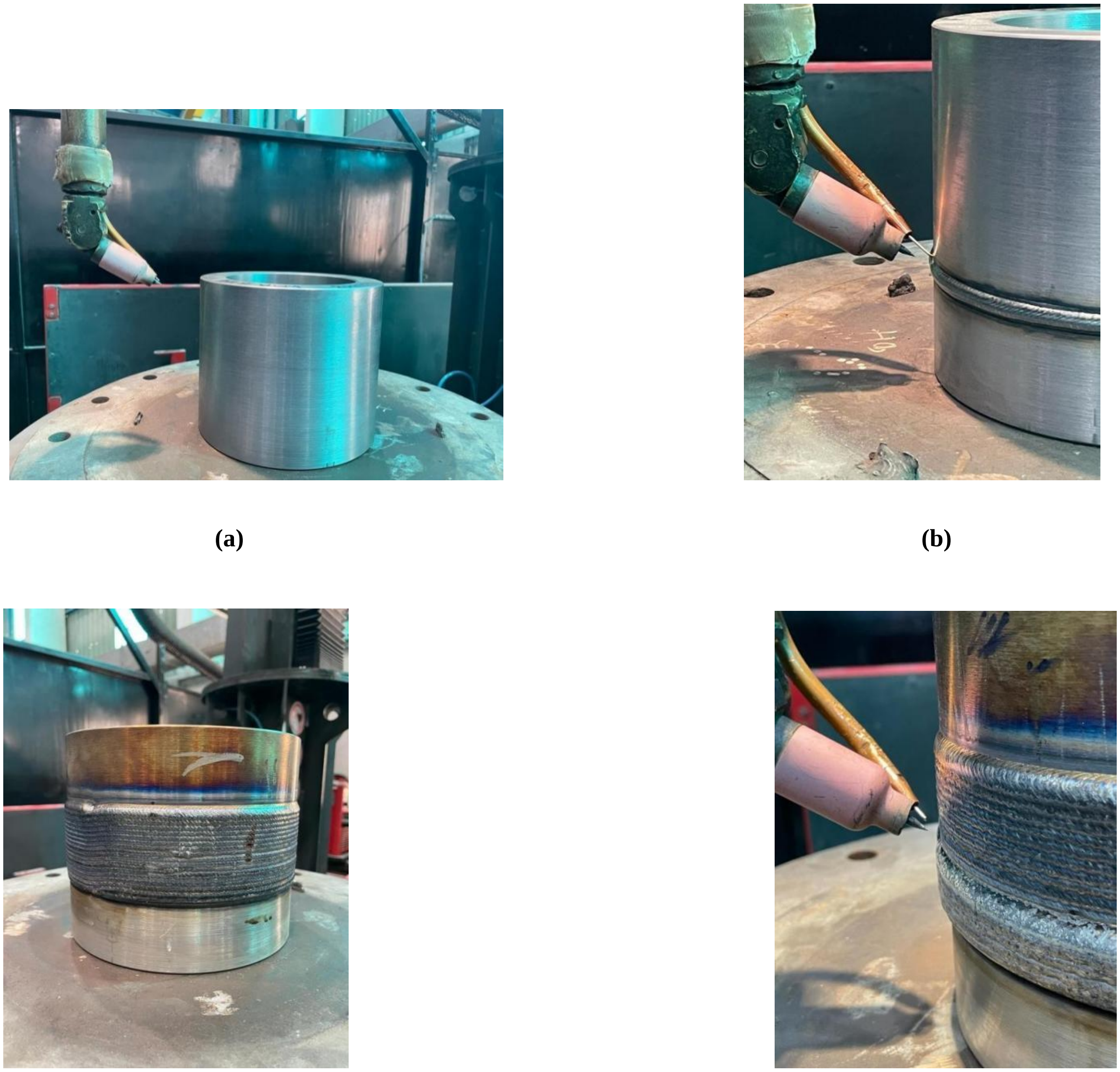
Aside from providing guidance to welders, a WPS and PQR also serve as vital documentation for quality control purposes. They offer a record of the welding process employed and the results of the qualification tests, which can be used to prove compliance with industry standards and customer requirements.

3. Welding of the specimens

To ensure the highest quality welds for testing purposes, it is crucial to carefully control the welding process. This involves selecting the appropriate welding procedure, materials, and equipment, and closely monitoring and controlling the welding parameters throughout the process.

One commonly used approach for welding specimens is the use of standardized welding procedures (SWPs). These procedures are developed by welding experts and provide detailed guidelines for performing a specific welding task. SWPs include information on the type of welding process, the materials and equipment to be used, and the welding parameters to be followed. By utilizing a standardized welding procedure, it is possible to ensure that the welding process is consistent and that the resulting welds are of a consistent quality.

In conclusion, cladding is a challenging welding process that demands meticulous attention to detail and an in-depth comprehension of welding fundamentals. By creating a welding procedure specification that considers the desired layer count and closely monitoring essential welding parameters such as interpass temperature, it is feasible to attain a superior quality clad material that satisfies the intended application's demands.



(a) **(b)**

(c) **(d)**

Fig.-5: (a) shows specimen before cladding, (b) 1st layer started, (c) 1st layer completed, (d) 2nd layer started

3.1 Testing Detail:

Sr. No.	Test Type	Test Method	Acceptance
1.	UT Examination	Ultrasonic test to check Weld Bond integrity During ultrasonic examination, the reference standard for examining and evaluating the weld bond integrity shall be 1/8" Flat Bottomed Hole (FBH) and for evaluating thevolumetric defects within the cladding/clad material shall be 1116* FBH.	No disbanding between base metal &Weld Metal
2.	Chemical Test	2.0, 3.0, 4.0 & 5.0 mm above Weld interface as per QW- 462.5(a) note No. 2, all element shall cover as specified for ERNiCrMo-4 of ASME Sec IIC	Calculate the PERNwith formula %Cr+3.3%Mo+16%N on each step &mention in report. Acceptance: 64 Minimum
3.	Guided BendTests	4 transverse side bend as pertable QW-453 of ASME Sec IX, Ed 2021	Acceptance as perASME Sec IX
4.	Impact Test	3 Specimen from base metal(HAZ), Test Temperature:-29°C(Minus 29°C) as per ASTM A370 Impact Direction: Transverse	20 Joule minimumaverage
5.	Hardness Test	Hardness test As per Vickers 10Kgf method ASTM E92, as per fig. Please check hardness on 3.0 & 5.0 mm from Fusion line, HAZ & parent metal as per below figure	Minimum Hardness (on weld 3.0 & 5.0 mm from base metal): 92 HRBW Maximum Hardness (weld 3.0 & 5.0 mm from base metal): 345 HV HAZ: 250 HV Base Metal: 250 HV
6.	Macroscopic examination	1 specimen per ISO 17639	Weld Shall show complete fusion with parent metal, surface pores s2 mm are permitted, liner Indications not permitted.

Additional testing: below test shall be done only after successful completion & acceptance of above test.

7.	Intergranular Corrosion Test	ASTM G28, Method B	Weight loss requirement of maximum 100 mpy
			(2.54 mm/ year) and no grain boundary attack inmicrostructure analysis.
8.	orrosiontest	As per ASTM G48, Method A at40 ÷ 1°C for 24 hours	Weight loss requirement ofmax. 4.0 g /Meter square andno pitting more than 25 microns at 20 X magnification
9.	Micro examination	1 specimen per 150 17639	As per materialUNSNO6625, cracks > 1,5 mm not permitted

Table Testing Details of Coupon

- Ultrasonic Testing: Ultrasonic Testing (UT) is a non-destructive testing method that uses high-frequency sound waves to detect internal defects, such as cracks or inclusions, in a material. In this study, UT examination was performed to detect any defects in the welded clad material.
- Chemical Testing: Chemical testing involves analyzing the chemical composition of a material. In this study, chemical tests were conducted to verify that the chemical composition of the weld overlay was consistent with the desired specification.

- Guided Bend Testing: Guided bend testing is a type of destructive testing that evaluates the ductility and soundness of a weld. In this test, a bend is made on the welded specimen, and any cracks or defects are evaluated visually.
- Impact Testing: Impact testing is a type of destructive testing that measures the energy required to fracture a material. In this study, impact tests were performed to evaluate the toughness and impact resistance of the welded clad material.
- Hardness Testing: Hardness testing involves measuring the resistance of a material to indentation or scratching. In this study, hardness tests were performed to evaluate the hardness of the welded clad material.
- Macroscopic Examination: Macroscopic examination involves evaluating the surface of the welded specimen with the naked eye or under low magnification. In this study, macroscopic examination was performed to evaluate the surface quality and uniformity of the weld overlay.
- Intergranular Corrosion Testing: Intergranular corrosion testing is a type of corrosion testing that evaluates the susceptibility of a material to corrosion along the grain boundaries. In this study, intergranular corrosion tests were performed to evaluate the corrosion resistance of the welded clad material.
- Pitting Corrosion Testing: Pitting corrosion testing is a type of corrosion testing that evaluates the resistance of a material to localized corrosion. In this study, pitting corrosion tests were performed to evaluate the corrosion resistance of the welded clad material.
- Microscopic Examination: Microscopic examination involves evaluating the microstructure of a material under high magnification. In this study, microscopic examination was performed to evaluate the microstructure and metallurgical bonding between the clad material and the substrate.

3.2 RESULTS AND DISCUSSION

The aim of this study was to create a welding procedure specification (WPS) for cladding Hastelloy C-276 onto carbon steel (WCB) using the gas tungsten arc welding (GTAW) process. The study's objectives were to optimize the welding parameters to achieve the desired quality and integrity of the weld, evaluate the impact of the process parameters on the welded cladding geometry, study the microstructure of the overlaid surface and substrate-coating interface, and perform mechanical and corrosion testing to assess the quality and durability of the weld.

To evaluate the quality of the weld, several tests were conducted, including ultrasonic testing (UT), chemical testing, guided bend tests, impact testing, hardness testing, macroscopic examination, intergranular corrosion testing, pitting corrosion testing, and micro examination. The test results were analyzed and discussed in detail in the Results and Discussion section of the report.

The welding parameters, including welding current, voltage, and travel speed, were optimized to achieve the desired weld properties. Welding current was found to be the most critical parameter affecting weld quality, as it determines the heat input, penetration depth, weld bead geometry, and formation of defects like porosity, cracks, and lack of fusion. Welding voltage and travel speed also played crucial roles in weld quality, affecting arc stability, penetration depth, and weld bead geometry.

According to the WPS, the welding current range should be 200-240 Amps, but the optimized value was found to be 210 Amps. The wire speed range should be between 170-220 cm/min, and the travel speed must be between 250-290 mm/min.

Current (Amps)	Wire Feed Speed (cm/min)	Travel Speed (mm/min)	Welding voltage	Heat input (KJ/cm)	Interpass Temp. (℃)
210	170 – 200	250 – 290	9 – 13	7.0	100

- **Chemical Analysis Test**

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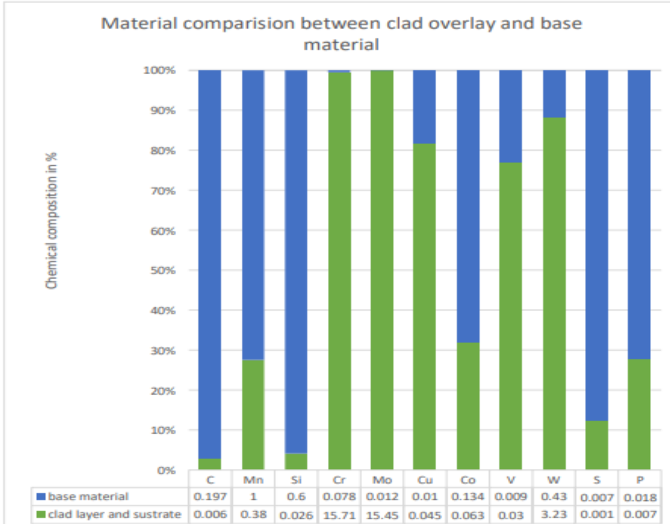

The details of specimen test are shown in table

Parameter	**Result**
Specimen location	On HAZ
Specimen orientation	Transverse
Specimen size (mm)	10X10X55
Test type	Charpy V notch
Dimension of striker tip (mm)	8
Nominal striking energy of pendulum (J)	400
Test temperature (℃)	-29
Absorbed energy (J) 1	16
Absorbed energy (J) 2	14
Absorbed energy (J) 3	16
Average of Absorbed energy(J)	15.33
Fracture appearance	Fully broken
Fracture appearance	Fully broken
Fracture appearance	Fully broken

Table Charpy test

- **Corrosion Test:**

Corrosion test conducted as per ASME Sec. IX Ed 2021
Corrosion Testing – IGC G28, ASTM G28 – Method B – 02(15)
Coupon Size: 168.97mm OD x 124.34mm ID x 300mm Lg +5.0mm CRO (Machined)

4. CONCLUSIONS

Based on the experimental findings and analysis, it is possible to conclude that cladding Hastelloy C276 on carbon steel (WCB) using GTAW process with the selected welding parameters is achievable and yields a high-quality cladded layer with good integrity. The use of Hastelloy C276 as a cladding material provides excellent resistance to corrosion and oxidation, making it an appropriate choice for various industrial applications. The welding parameters, such as welding current, voltage, and travel speed, significantly impact the quality and integrity of the weld. Optimizing these parameters is crucial to achieving the desired quality and minimizing the risk of defects such as porosity and cracks.

The microstructure of the cladded layer demonstrated ferrite grains with perlite at the grain boundaries, signifying good bonding between the cladding material and the base metal. The absence of cracks in the macro examination and side bend tests confirmed the excellent bonding and integrity of the weld.

The tests conducted, including UT examination, chemical test, guided bend tests, impact test, hardness test, macroscopic examination, intergranular corrosion test, and pitting corrosion test, all confirmed the quality and integrity of the cladding layer and the base metal. The results of the hardness and impact tests were positive and satisfactory, indicating that the cladded layer can withstand various mechanical stresses.

In summary, the experimental work on cladding Hastelloy C276 on carbon steel (WCB) using GTAW process has demonstrated that the chosen welding parameters significantly impact the quality and integrity of the weld. The selection of materials and preparation of specimens were critical in achieving the desired results. The microstructure of the overlaid surface and substrate-coating interface showed good fusion with no cracking, and the macro examination showed complete fusion with no cracks between the weld and HAZ. The results of the UT examination, chemical test, guided bend test, impact test, hardness test, macroscopic examination, intergranular corrosion test, and pitting corrosion test demonstrated that the welded cladding met the requirements of industry standards and codes.

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