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ASSESSMENT OF CORROSION RESISTANT ALLOY (CRA) CLAD MATERIAL FOR GEOTHERMAL WELLHEAD PIPING SYSTEM

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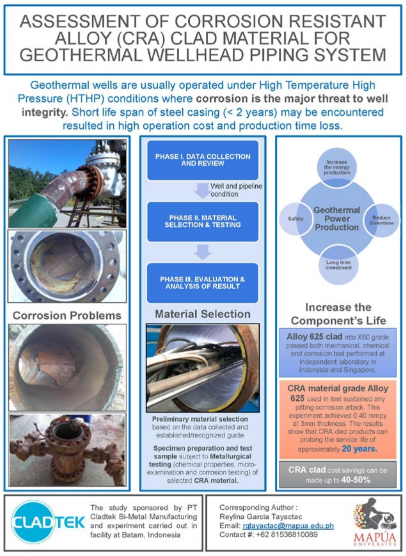
Graphical abstract


ASSESSMENT OF CORROSION RESISTANT ALLOY (CRA) CLAD MATERIAL FOR GEOTHERMAL WELLHEAD PIPING SYSTEM

Geothermal wells are usually operated under High Temperature High Pressure (HTHP) conditions where **corrosion is the major threat to well integrity.** Short life span of steel casing (< 2 years) may be encountered resulted in high operation cost and production time loss.

Preliminary material selection based on the data collected and established/recognized guide

Specimen preparation and test sample subject to **Metallurgical testing** (chemical properties, micro-examination and corrosion testing) of selected **CRA material.**

Alloy 625 clad into X60 grade passed both mechanical, chemical and corrosion test performed at independent laboratory in Indonesia and Singapore.

CRA material grade Alloy 625 used in test sustained any pitting corrosion attack. This experiment achieved 0.40 mmpy at 3mm thickness. The results show that CRA clad products can prolong the service life of approximately **20 years.**

CRA clad cost savings can be made up to **40-50%**

The study sponsored by PT Cladtek Bi-Metal Manufacturing and experiment carried out in facility at Batam, Indonesia

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Abstract

The geothermal power industry has reported a wide range of corrosion problems. Given the extremely corrosive conditions to be treated in the geothermal sector and the benefits of reduced unplanned downtime when used, operating cost savings would be expected if more CRAs clad products were used. The selection of suitable Corrosion Resistant Alloy (CRA) material is vital for plant operability, especially in challenging well conditions with low pH value and carbon dioxide, hydrogen sulphide, and hydrogen chloride content. The primary examined material alloy 625 given its exceptional erosion and corrosion resistance. Alloy 625 was selected based on a preliminary material selection review of its mechanical and chemical properties to withstand a corrosive environment. The study method emphasizes selected material from dissimilar alloying steel grades (e.g. Backing Steel + CRA material) based on its mechanical properties, chemical composition, macro and micro examination, and corrosion resistance using the common industrial standards. The study focuses on using Alloy 625 cladding using the overlay method to determine the weld overlay's suitability for the geothermal production system. The weld overlay cladding is performed to increase the components' life and as a replacement using an expensive corrosion resistant solid material. In many cases, only the surface of the material requires corrosion resistance and carbon or alloy steel can be clad with a more corrosion-resistant alloy. Up to 50% of the cost of using the solid alloy can be saved by cladding. This study also describes the technical and economic advantages of using Alloy 625 clad material in the present condition.

Keywords: Corrosion Problems, Corrosion Resistance, Corrosion Testing, CRA Weld Overlay Cladding, Geothermal

1.0 INTRODUCTION

Geothermal energy is essentially inexhaustible because it draws heat from the earth and its greenhouse gas emissions are negligible compared to fossil fuels. Its possible negative environmental consequences are negligible due to the removal of hydrogen sulfide from high-temperature steam and the disposal of spent geothermal fluids into the soil. As the Philippines is part of the "Pacific Ring of Fire," it is rich in geothermal resources.

Dissolved carbon dioxide (CO2), hydrogen sulphide (H2S), and ammonia (NH3) contain geothermal fluids and chloride ions, which can cause metallic material corrosion. Therefore, the safe use of geothermal systems depends on especially when choosing materials. Precautions and conscious selection of materials at the design stage play an important role in reducing corrosion effects. Optimal cost and safety are factors that affect material selection. Construction costs, operating assets, operation, lost production, and repair costs directly impact the selection of materials.

There are numerous geothermal fields worldwide due to acidic fluid, where the wellbore and wellhead components made from the standard carbon steel have experienced excessive corrosion [1]. In the Philippines, the Sodium Hydroxide (NaOH) solution was injected into the well with capillary Titanium or Alloy 625 tubing to neutralize the reservoir and zone insulation to mitigate the acidic source.

Using steam collection and well-case acid resistant structural materials, acid wells marketing techniques would involve high initial fixed costs that are not feasible in third-world countries such as the Philippines. In the same way, the cost of converting geothermal energy into power is high, which would make it less favorable than other sources of energy. In recent geothermal efforts of power generation companies to extract the injection assembly from the well, the commercial mitigation operation has to be stopped for safety considerations.

Geothermal wells are usually operated under High Temperature High Pressure (HTHP) conditions where corrosion is the major threat to well integrity. As a result, high operation cost and production time loss due to a short life span of steel casing reported in less than 2 years. The selection of suitable CRA materials is vital for plant operability, especially in challenging well conditions, e.g., low pH, high CO2/H2S/HCl content, and well longer life. However, for the systematic selection and qualification of materials, there is a lack of established guidelines specifically for geothermal use. CRA selection is often based on limited data from literature or empirical testing on a case by case basis, which is time-consuming, costly, and often leads to overly conservative solutions.

The research aim is to assess the suitability of CRA weld overlay cladding and its benefits in enhancing the corrosion resistance of acidic wellhead piping system for geothermal application. This research provide a corrosion assessment of the CRA Clad material to replace the costly solid CRA in the defined geothermal wellhead piping system to solve corrosive problems and bear extremely corrosive conditions using geothermal steam in the volcanic setting. The primary examined materials are alloyed steels, given their exceptional erosion and corrosion resistance. The methodology emphasized the selected materials from dissimilar alloying steel grades (e.g. Backing Steel + CRA material) based on its chemical composition, micro examination, and corrosion resistance using the common industrial standards.

The study ignored carbon steel and focused on alloyed steels (Solid and CRA clad) based on its corrosion performance and more suitable geothermal systems applications. Therefore, nickel alloy 625 material has been selected for this study. The equivalent material reference of the selected grade is the exact chemical composition, corrosion and mechanical properties of the selected grade.raffic management and accident management is very important for human in congestion city in order to provide comfortable lifestyle and safety. By having this system, people will haved real-time information on traffic condititionaround the city, which can avoid from stuck on traffic jam. At present, ground-based solution are widely used to monitor traffic condition in a small and fixed coverage area which is stationary and short view sight.

2.0 CORROSION PROBLEMS

Several factors influence geothermal power plants' equipment and power generation in the Philippines, such as scaling, erosion, sludge accumulation, microbiological fouling, and algal forming. Higher expense on preventive maintenance work, cooling water treatment chemicals, and plant rehabilitation is needed to prevent or control occurrences [2]. Gazo and Datuin has said the corrosion could cause equipment deterioration and perforation due to product loss, low operating efficiency, lost time for maintenance and replacement, and power generation output (1989) [2]. Corrosion varies with the temperature, chemical composition, geothermal steam flow rate - geothermal source and the selected energy cycle, and the geothermal brine contains hydrogen chloride ions. Hydrogen carbon dioxide, ammonia, sulfate, and oxygen produce many corrosive effects on the plant's metal components.

Geothermal system fluids include dissolved carbon dioxide, hydrogen sulphide and and chloride ions that may cause corrosion. Therefore, safe application is significantly affected by selecting appropriate material. Precautions during the design and careful selection of materials play an essential role in mitigating corrosion's effects in the production system. Optimal cost and safety are both considerations in the selection of materials. Construction costs, operating assets, operating costs, lost production costs, and repair costs directly influence material selection. Operational experience in geothermal fields and experimental studies involving the consumption of actual geothermal fluids are the basis for material selection. In this report, the types and factors of corrosion observed in geothermal systems and the conditions of metal and non-metallic materials found in geothermal systems were considered.

3.0 MATERIAL SELECTION

According to the Norsok Standard design principles in 1994, the materials used should be optimized based on investment and operating costs to minimize the life cycle cost (LCC) while ensuring acceptable safety and reliability. The main factors considered in selecting material are: (1) Material with good market availability and recorded manufacturing and service efficiency. (2) Reducing the number of materials considering the costs, interchangeability, and availability of the necessary spare parts. (3) Lifespan and service condition. (4) Capability with materials and corrosion protection techniques against related corrosion conditions. (5) Require system availability. (6) Applied maintenance system and the extent of machine redundancy. (7) Loss weight consideration. (8) Monitoring of corrosion. (9) Climate impact including the compatibility of different materials. (10) Assessment of the possibility of failure, criticalities, and effects. Consideration should be given to any adverse effects that material selection may have on human health, environment, protection, and material properties. (11) Environmental concerns associated with corrosion inhibitors and other chemical treatments [3].

Carbon Steels

As a result of their low cost and varied ease of use, carbon steels are a distinct initial consideration for selecting materials, particularly for thick-walled pipe systems where a degree of material loss can be tolerated. Though, the chance of localized corrosion or cracking will pose a major risk in all structures. For conservative projects where pH values are greater than 6, and $Cl^–$ concentrations are smaller than 2%, uniform corrosion may be observed at a rate of 1-10 mpy / 25-250µm per year. However, if pH and chloride concentration rise, there is a higher risk of pitting corrosion. The presence of any composite would be accelerated by the presence of oxygen in the solution increases the rate of uniform corrosion and pitting. Fluids that flow quickly and have large particles cause erosion and corrosion. Thus, the permissible carbon steel flow rate is typically between 1 and 2 cfm / 0.5-1 m/s.

Stainless Steels

Observably, the usage of stainless steel against carbon steel reduces the risk of uniform corrosion in the geothermal fluid climate. As such, more serious corrosion problems can still arise, such as pitting, stress corrosion cracking and erosion, and conditions-dependent corrosion.[4] The increase in Cl-concentration increases local corrosion, while the increase in temperature increases the risk of pitting corrosion. The resistance of stainless steel to pitting and cracking corrosion depends on its contents of Cr and Mo. Alloys of higher alloy grades, such as alloy 2205, alloy 32750, alloy 32760 and Ferralium® 255, are also more inclined to low alloy grade 316 alloys. Increased content of alloys can also enhance resistance to pitting. It is usual for many grades to be used in combination during the project, and as the temperature decreases.

Nickel Alloy

In the case of increased corrosion or increased temperature, while alloys' expense increases, geothermal fluids typically require frequent use of nickel alloys on stainless steel. As the maximum working temperature of super-duplex stainless steels is 250 °C, Ni-Cr-Mo alloys such as Alloy 625 and Hastelloy C-256 are used. This alloy provides extreme corrosion resistance while having a higher degree of resistance to pitting than other super-duplex stainless steels.

Titanium

Regardless of the cost, titanium and titanium alloys have been successfully deployed in geothermal plants' most violent regions. The corrosion concentrations were usually smaller than 0.3 mpy/7µm each year, with a marked increase in erosion and corrosion at an increase in temperature, Cl– concentration or flow rate. Titanium is therefore tough to cavitate and inflict damage to the impact. The pitting can be seen where Cl-concentration is >10 percent, and here various titanium alloys can give long-lasting features, such as Gr 29. This material has a service life expectancy of more than 15 years and no renewable costs relative to low alloy steel, nor does it shape corrosion and amassing goods containing nuclear and heavy metals. Also, titanium is the preferred alternative for oxygen consumption since oxygen-containing fluids, and hot Cl-ion fluids can induce part defects in both stainless steel and nickel alloys. In certain situations, titanium alloys are used in well-headed pumps, pressure gauges, cylinders and blow-out preventers.

3.0 CORROSION RESISTANT ALLOY CLADDING

For more than 40 years in the chemical, petrochemical, and oil refining industries, the notion of carbon steel clad with a relatively thin layer (usually 2-3mm) of CRA has been well known for vessels, separators, heat exchangers, tanks, etc. The use of CRA-clad products in pipelines has increased over the past 20 years, especially in the oil and gas industry.

Cladding is a method of depositing on carbon or low alloy steel base metal a comparatively dense coating of filler material. By allowing the use of a low-cost, more machinable base material coated with costly metals and alloys to obtain the desired properties in particular product fields, this increases manufacturing economies. Two-fold purposes can be used for cladding on a surface; first, to strengthen surface-dependent properties such as wear resistance under abrasion, degradation, and corrosion, and the other is to strengthen the bulk-dependent properties such as hardness, strength, etc., known as hard faced. Clad components are likely to have the potential to economically perform their particular purpose over a fairly long duration in a hostile climate. In various industries such as chemicals, mines, agriculture, power generation, pressure vessels, etc., there is a growing demand for clad components every day. On the other hand, tool makers use cladding processes to create tools such as rollers, dies, jaws, etc. that should have high hardness and strong compressive strength. One common and flexible approach is cladding by welding.

Weldability of Metals

When welded with or without adding pressure, two metal sections of the same or different metals are combined and joined, with or without the use of filler metal, and thus the ease with which the metal joint correctly connects metal or metals is called weldability. The technique that makes welding a given material simple without creating any defects is called weldability. The ability to weld metal under production conditions which are satisfactorily added to the intended surface is also specified. Weldability is considered to be the simplicity of producing a suitable welding joint and can be measured by the consistency of the welding joint, the effort and the expense of creating the welding joint.

While the metal structure's properties determine the efforts needed to develop sound weld joints, including melting point, coefficient of thermal expansion, thermal and electrical conductivity, base metal defects, and surface condition. Thus, weldability is considered to be a subjective term for a metal. The metallic material with sufficient weldability should achieve the criteria such as good welding efficiency and high dilution, with the same corrosion resistance and no embrittlement when stress relief.

The principles of weldability are: (1) The metallurgical compatibility of the metal\alloy to be welded to some particular welding procedure. Metallurgical consistency ensures that the base metal and the welding metal can be mixed with the degree of dilution found in a particular process without creating deleterious materials and stages. (2) The ability of the metal \alloy to be welded with mechanical sound. Mechanical soundness must follow the criteria of soundness and normal engineering norms. (3) The operation capacity of the resultant welded joint. Serviceability can be linked to the welded structure or joint ability to perform under low and high temperature impacts, respectively.

The variables affecting weldability are: (a) Material with a low melting point can be welded very quickly. (b) Material with high thermal conductivity (K) is treated as difficult to weld. (c) Reactivity of materials with air, water or surroundings becomes difficult to weld. (d) A high coefficient of thermal expansion is difficult to weld. (e) The high electrical resistance of the material is problematic because it needs a lot of heat energy. (f) The material surface condition if dirty it is difficult to weld. (g) Metal strength and brittleness at high pressure. (h) Metal structure. (i) Heat treatment is done before and after welding. (j) Metal thermal properties.

From the factors listed above, whatever the material is affected by the most significant number of factors, the corresponding material is treated as very difficult to weld. Whatever the material is affected by the least number of factors, the corresponding material is treated as very easy to weld. Some materials are easily weldable, but some are difficult to weld. Metals that are weldable (in descending order) are iron, steel, cast iron, low alloy steel, stainless steel, and alloy 625. The importance of good weldability has produced mechanically sound, crack-free welding joints. It is used in the fabrication process to make the joint strong and produce high quality. Specialty metal welding is not necessary for the welding of metal. There are no longer hot runs, reducing the need for preheating. Demonstrates ability to serve the demands of the client's expectations.

Alloy 625 has a high alloy content, making it resistant to the most severe corrosive environments. In slightly alkaline conditions, fresh and seawater and neutral salts there is almost no attack. The mixture of nickel and chromium in low concentrations protects oxidizing compounds, while the high nickel and molybdenum contents provide defense against non-oxidizing compounds. High molybdenum concentration also makes this alloy very resistant to pitting and crevice corrosion, and niobium prevents intergranular cracking, ensuring more stability. Additionally, the nickel content in the alloy offers corrosion safety in chloride stress corrosion cracking. This alloy mixture exhibits corrosion resistance properties over a wide variety of corrosive environments. For instance, it has been suggested as a material of construction to handle liquid corrosives such as hydrochloric and nitric acids, two separate corrosive types of chemicals. Many products can take on the properties of either one of these acids when combined with the other.

Alloy 625 prevents oxidation and scaling over a wide range of temperatures. Its performance in an extremely severe test is demonstrated in comparison to other materials in Figure 1. In this test, periodic weight-loss determinations show that the alloy is able to maintain an oxide coating at high temperatures under dramatic cycles of loading. 1800°F is a temperature at which an increasing resistance becomes an important consideration for materials.

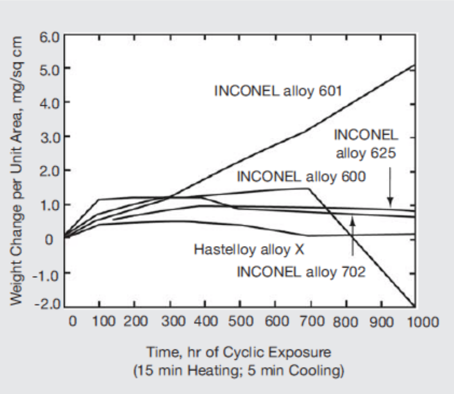

Figure 1 Scaling Resistance at 1800°F (Special Metals, 2013) [6]

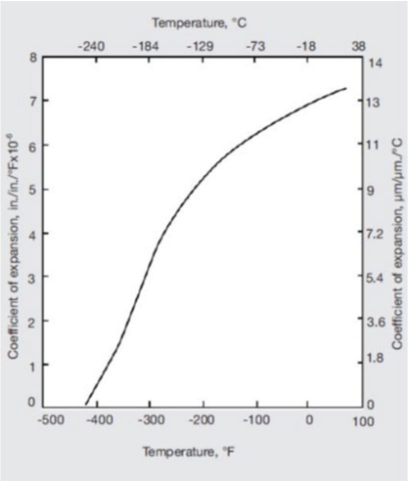

Figure 2 Thermal Expansion at Low Temperature (Special Metal, 2013) [6]

Some physical constants and thermal properties of INCONEL alloy 625 are shown in Table 1 and Table 2 Low temperature thermal expansion, based on measurements made by the National Bureau of Standards, is shown in Figure 2.

Table 1 Physical Constant of Alloy 625 (Special Metals, 2013) [6]

Density, lb/cu in (gram/cc)		0.305 (8.44)
Melting Range, °F (°C)		2350-2460
Specific Heat[a], Btu/lb°F (J/kg°C)		1290-1350
	0°F (-18°C)	0.096 (402)
	70°F (21°C)	0.098 (410)
	200°F (93°C)	0.102 (427)
	400°F (204°C)	0.109 (456)
	600°F (316°C)	0.115 (481)
	800°F (427°C)	0.122 (511)
	1000°F (538°C)	0.128 (536)
	1200°F (649°C)	0.135 (565)
	1400°F (760°C)	0.141 (590)
	1600°F (871°C)	0.148 (620)
	1800°F (982°C)	0.154 (645)
	2000°F (1093°C)	0.160 (670)
Permeability at 200 Oersted (15.9 kA/m)		1.0006
Curie Temperature, °F (°C)		<-320 (-196)

[a] *Calculated*

Table 2 Thermal and Electrical Properties (Special Metals,2013) [6]

Temp. °F	Mean Linear Expansion[a] 10-6in/in•°F	Thermal Conductivity[b,c] Btu•in/ft2-h•°F	Electrical Resistivity[c] ohm-circ mil/ft
-250	-	50	-
-200	-	52	-
-100	-	58	-
0	-	64	-
70	-	68	776
100	-	70	780
200	7.1	75	794
400	7.3	87	806

600	7.4	98	812
800	7.6	109	818
1000	7.8	121	830
1200	8.2	132	830
1400	8.5	144	824
1600	8.8	158	818
1700	9.0	-	-
1800	-	175	812
2000	-	-	806

[a]From 70°F to temperature shown [b]Measurements made at Battelle Memorial Institute [c]Material annealed 2100°F/1 hr

For over 40 years from the reviewed literature, alloy 625 compositions shown in table 3 have been commonly used nickel based alloy originally for turbine and later to many successful applications such as cladding, surfacing for marine industry and for tool and die steel as hard facing solution.

Alloy 625 was originally designed to be a solid solution alloy and is considered one for most applications. It is marketed on the basis that its strength is derived from the stiffening effect of molybdenum and niobium on its nickel-chromium matrix; therefore precipitation-hardening (age-hardening) treatments are not required.

In 1987 at the annual AWS meeting held in Chicago, Cieslak's paper identified the development of the metal welding microstructure and the solidification cracking action of Alloy 625 gas tungsten arc (GTA) welding as a function of composition. A three-element, two-level, factorial alloy design category involving elements C, Si, and Nb has been studied. The inference is that the increased temperature range of solidification and the development of Nb-rich eutectic structure are the key reasons for Nb alloys' increased susceptibility to crack solidification. Niobium-free alloys have been shown to have a lower significant implication to solidify hot cracking, but the contributions of C and Si to these alloys have been dangerous. [5]

Table 3 Limiting Chemical Composition (%) of Welding Products (Special Metal, 2013 [6]

	INCONEL Filler Metal 625	**INCONEL[a] Welding Electrode 112**
Nickel	58.0 min.	55.0 min.
Carbon	0.10 max.	0.10 max.
Manganese	0.50 max.	1.0 max.
Iron	5.0 max.	7.0 max.
Sulfur	0.015 max.	0.02 max.
Silicon	0.50 max.	0.75 max.
Chromium	20.0-23.0	20.0-23.0
Niobium (plus Tantalum)	3.15-4.15	3.15-4.15
Molybdenum	8.0-10.0	8.0-10.0
Aluminum	0.40 max.	-
Titanium	0.40 max.	-
Cobaltc	-	0.12c
Phosphorus	0.02 max.	0.03
Copper	0.50 max.	0.50 max.
Other	0.50 max.	0.50 max.

[a]Deposited weld metal. [b]Plus cobalt. [c]When specified.

Alloy 625 is easily joined by conventional welding processes and processes. The filler metal alloy 625 and electrode alloy 112 are designed for welding alloy 625 to itself and to other materials. Compositions of the two chemicals are presented in Table 2.3. Like alloys 625 and 625L, both types of deposit weld metals are extremely resistant to corrosion and oxidation and have high strength and hardness from cryogenic temperatures to 1800 degrees Fahrenheit. Post weld heat treatment is not needed to maintain its high strength and ductility. When being welded with alloy 625, both materials withstand high dilutions and retain their own special properties.

4.0 CRA CLADDING PROCESS

Clad pipes consist of a layer of steel with an outer layer of steel bonded to it. Different manufacturing processes (e.g. hot rolling or welding overlay) are used to bind the CRA layer to carbon steel. Unlike clad pipes, lined pipes have a CRA liner that is mechanically bonded to the carrier pipe.

Roll Bonding

Two or three layers of different materials need to be properly cleaned during the roll bonding process and moved through a pair of rolls under adequate pressure to bond these layers. The working strain is high enough to bend the metal and decrease the average thickness of the cladding material. It is necessary to use heat, especially if the ductility of the metal is not adequate. For example, you can control paper sheets' adhesion by drawing patterns on a piece of paper. When the board is heated and the coating vaporizes, only the bare metal surface is bonded, and the unbonded part can expand—this process is typically used for the manufacture of heat exchangers for refrigeration equipment.

Explosion Welding

In the explosive welding process, the two layers' bonding pressure is caused by an explosive chemical sheet's detonation. In the bond between metals, there is no heat-affected region. The explosion expands through the board, and helps to eliminate from between the sheets impurities and oxides. Pieces typically to size 4 x 16 meters can be made. This process is useful for covering a corrosion-resistant layer of a metal plate.

Weld Overlay Cladding

In the oil and gas industry, welding overlay cladding materials are widely used and can be used for various components such as pipes, valves, fittings and pressure vessels. Although many components seem to have the same amount of built-in corrosion allowance, the waste rate can still be too high for certain materials. Therefore, the surface layer provides surface protection while still allowing the internal components to have sufficient strength to comply with the relevant specifications and standards. Various welding processes can be applied, the most common method by gas tungsten arc welding (GTAW). Other method used also include manual metal arc (MMA), laser deposition, submerged arc welding (SAW), plasma arc welding

(PTAW), flux arc welding (FCAW), and submerged arc welding (SAW).

5.0 METHODOLOGY

The research focus of the study was on steel materials Alloy 625 currently available widely on the market and used in various industries as construction materials for pipes and different equipment elements. Depending on the content of their alloy components, such as chromium, molybdenum and nickel, selected type of steels has been selected as representatives of different grades due to their significant influence on the materials' corrosion behavior. The study ignored carbon steel and focused on alloyed steels (Solid and CRA clad) based on its corrosion performance and therefore more suitable applications in geothermal systems. Therefore, nickel alloy 625 material has been chosen for this study. The cross-reference of the selected grade equivalent materials are the exact chemical composition of the selected grades, corrosion and mechanical properties.

Phase 1: Gathering of Data Information

Gathering information is the first part of the methodology. In the geothermal power industry and related agents, this stage will help to recognize the corrosion problems. This includes identifying common construction materials used in geothermal systems such as piping and wellhead components. The common problem was corrosion and erosion in geothermal.

Step 1. Well and pipeline data collection for review

Corrosion is a major concern for steel piping, which is why carbon steel is the most widely used material for geothermal pipelines. These data, like the elements that cause corrosion, are critical for material shortlisting. To avoid inadequacy when performing assessment, the data collected should be as accurate and as close to the actual condition as possible. When the information has flaws, conservative solutions are favored. Fluid chemistry (partial pressure of H2S and CO2, mass flow rate, pH of the condensate/liquid phase, concentration of chloride and buffer agents, presence of sulphur/incompatible elements, and oxygen/contaminants), material design philosophy, and inspection results are typical data collected.

From the study conducted by Litchi et al. in 2010, the water phase chemistry in the below table also showed a significantly higher value of SO4=, Fe, and Mg typical of acid wells in the area. The high Fe in the discharge could have come from the corrosion of the carbon steel casing itself. Table 4 and Table 5 summarizes the water and gas concentrations at different periods. The H2S level of the MG-9D well was the highest among the Mahanagdong wells.

Phase II: Material Selection and Testing

The second phase of the research methodology is to conduct a preliminary material selection of suitable corrosion resistant alloy for geothermal wells, which are typically operated under (High Temperature High Pressure) HTHP conditions. Selection of appropriate CRA materials is essential for plant operability, especially in challenging well conditions, such as low pH, high CO2 / H2S / HCl content, and long well life.

Step 2. Preliminary Material Selection

Shortlist material based on the limitations listed in internationally recognized standards, books or databases. The standard references for this research such as ISO standards and ASM handbook.

Table 4 MG-9D water chemistry [1]

Data	**Previous Discharge Data**		**1999 Discharge Data**			
	26-Apr-94	18-Feb-95	4-Jul-99	24-Aug-99	26-Aug-99	7-Sep-99
WHP(MPaa)	1.874	2.693	0.838	0.838	0.838	0.993
H (KJ/kg)	1287	1554	1122	1122	1122	1152
SP (MPaa)	0.48	0.48	0.793	0.903	0.903	0.943
pH (25°C)	**3.11**	**3.24**	**3.43**	**3.16**	**2.87**	**4.05**
Na	3117	3450	3039	2782	3362	2836
K	950	1200	617	538	668	564
Ca	82	90	72	96	94	92
Mg	25	16.8	10.8	10.7	12.1	10.4
Fe	282	53	96.7	65.4	69.8	69.2
Cl	6175	6415	5263	5046	6088	4947
SO_4	508	101	300	310	380	315
B	21	23	54	56	64	49
NH_3	15.6	19.4	11.9	9.66	12.1	13
SiO_2	910	1003	571	575	691	569
H_2S	1	2.2	5.8	3.3	1.4	3.8

Note: Compositions unit in mg/kg

Table 5 MG-9D gas chemistry [1]

Data	Previous Discharge Data		1999 Discharge Data			
	26-Apr-94	18-Feb-95	4-Jul-99	24-Aug-99	26-Aug-99	7-Sep-99
WHP(MPaa)	1.874	2.693	0.838	0.838	0.838	0.933
Enth (KJ/kg)	1287	1554	1122	1122	1122	1152
SP (MPaa)	0.48	0.48	0.793	0.903	0.903	0.943
CO_2	400	628	120	165	195	184
H_2S	24.3	36.3	16	9.6	10.7	18.4
N_3	0.05	0.03	0.01	0	0	0.2
He	0	0	0.05	0	0	0
H_2	0.082	0.646	1.313	2.682	3.381	10.47
Ar	0.05	0	0.32	0.04	0.03	0
N_2	12.67	4.213	1.282	2.306	1.623	9.559
CH_4	0.65	1.02	0.13	0.43	0.39	1.66

Note: Compositions unit in mmole/100 moles steam

Step 3. Standard Material Assessments

Standard material assessment & tests act as QC for the shortlisted material regarding suppliers, incoming materials batches/heat, weldment, and traceability. Standard testing helps eliminate the substandard material and unsuitable alloy for the further selection process, reducing total material qualification & selection process duration and costing. The following metallurgical tests to be carried out in this study include chemical properties, micro-examination and corrosion testing of selected CRA clad materials (Alloy 625).

Step 4. Specimen Preparation and Experimental Procedure

This procedure defines the sequence and the administrative controls of test coupon preparation and experiment. In this phase, the researcher selected a high tensile CS material as a substrate to be overlayed with CRA weld metal. CRA welding was performed by deposition of a single layer, overlaying steel components in 1G or 2G positions, using the GTAW Hot-Tig wire feed process. The filler metal and base metal used in this study were the alloy 625 and the API 5L Gr. X65 steel, respectively.

Phase III: Evaluation and Analysis of Result

In this study laboratory test has performed for further assessment for material that is survived or accepted by standard material assessment. The test include mechanical test, chemical analysis, and corrosion testing, macro and micro examination. Customized testing is specially designed to simulate the actual operating condition, based on the data collection from the step 1 (with respect to H2S, CO2, pressure, temperature, pH, Chloride, acids, etc). In a typical HPHT test, the sample is loaded in autoclaves under simulated condition, followed by corrosion rate, pitting, and intergranular evaluation at the end of test duration. Depending on well condition and project need, dynamic testing in the lab such as a rotating cage and flow loops may be considered to include the effects of flow rate and shear stress. Materials are evaluated for their relative performance demonstrated from qualification test based on specific criteria (e.g. corrosion rate at defined pressure/temperature rating, cracking susceptibility at H2S concentration, etc). For further optimization, cost of workover and stop production may also be included to evaluate the total life cycle cost. Both technical and economical view has been presented in conclusion section of this study.

Materials and Methods

In this study, the carbon steel material used API 5L X60 – 10" OD x 9.27 mm nominal WT, Pipe HN: 186711 and filler metal: ERNiCrMo3 (UNS N06625); wire diameter 1.2mm, Trade Name: Raajratna 625 (HN: RJ274), for welding procedure qualification test (WPQT).

Based on the actual material test certificate, Table 6 shows the chemical composition of the two materials. This composition was used as a reference data validation on the laboratory chemical test.

Table 6 Chemical Composition of the Two Materials Based On Actual Material Test Certificate (MTC)

Item	**Chemical composition (wt.%)**							
Filler Metal (Alloy 625)	Ni	C	Cr	Mo	Nb	Fe	Mn	Si
	65.50	0.010	20.0-23.0	8.0-10.0	3.15-4.15	0.26	0.040	0.040
CS Pipe (API 5L X60)	C	Si	Mn	P	S	V	Nb	Ti
	0.06	0.27	1.37	0.07	0.022	0.04	1.37	0.27

Welding Preparation

In this study, an automatic TIG welding process was used. Figure 3 below illustrate the automatic TIG welding setup with its main components. In cladding the coupon, the parameter used for mechanized TIG reference to Cladtek welding procedure no. CT-00-WPS-1152 Rev.0 and supporting PQR No. CT-00-PQR-651. Figure 4 illustrates a typical weld overlay sequence, in which the first CRA layer is usually deposited to a thickness of 1.5mm-2.0mm, followed by a subsequent layer. To meet the iron dilution requirements in weld overlay cladding, a minimum of 3mm CRA clad thickness is required.

Figure 3 Automatic TIG welding set up with its main components

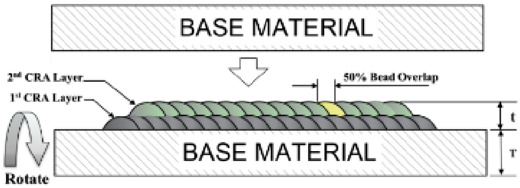

Figure 4 Typical weld overlay sequence

Figure 5 Surface preparation and cleaning by blasting pipe internal (a) UT Thickness check of CS Pipe before welding (b), setting material (c) and start weld overlay cladding (d).

Figure 5 shows the weld overlay cladding process starts with surface preparation and cleaning of internal pipe surface subject to cladding. The pipe internally blasted in full length using the automatic blasting machine. The acceptance criteria to meet SSPC SP10 or equivalent to ISO 8501-1 Sa 2.5 followed by external and internal surface inspection of the bare pipe before cladding. UT Thickness check of CS pipe before welding to check the thickness of CS, including any pre-machining area, is associated with CRA thickness calculation after weld overlay. To check the thickness of CS, including on pre-machining area and associated with CRA thickness calculation after weld overlay. Mark the external surface of the pipe for every point that will be checked. When using the UT method for UT thickness, the frequency and number of locations - pipes checked at 1M intervals (0, 90, 180, 270 deg per location). Perform weld overlay as per length in the drawing. Weld overlay cladding shall be deposited by GTAW process; at least two welding passes are required. The pipe jacket was used to minimize the shrinkage. The welding operator directly inspects pipes by video camera and checked by the welding inspector on the rig. The NDE will conduct once passed the visual inspection.

Evaluation Process – NDE

There are two methods of DPT/LPT is practiced. The solvent removable method used to all accessible overlay surface fittings, flanges, pipe ends and Water Washable method for inaccessible surfaces i.e., pipe internal overlay. LPT performed according to ASTM E165, ASME V and VIII Div.1 / 2, API 6A PSL3 and DNV OS F101 Table D-4.

The process shows in Figure 6 started with preliminary surface preparation by high pressure water wash and followed by Red Dye penetrant application. The dwell time for penetrant is 15 minutes after red application end to end, the pipe keep in slow rotation during the dwell. The removal of excess penetrant by water wash with controlled pressure (<50 psi) and drying of wet surface with low pressure air nozzle, the next and last process is application of developer. Interpretation after 10 minutes of application with a video camera and monitor. Identification and marking of defects, if any on pipe OD, the NDE personnel recorded inspection videos.

Figure 6 Liquid Penetrant Test – Water Washable Method (a), UT Disbondment Inspection (b)

UT lamination and disbondment between weld overlay and CS backing pipe/fitting checked by scanning from the external surface full length. The process use of 3mm to 10mm FBH for calibration per ASME / DNV standards; Perform UT thickness checked at the same spot as before overlay, and the difference in values before and after is calculated as CRA thickness. Weld overlay thickness is also determine by Induction Magnetic methods i.e., with Elcometer. Performed Positive Material Identification (PMI) - Chemical Composition Check on weld overlay surface, at ends of pipe 6 inch and above by trained QC Inspector Weld overlay chemical composition according to ASME Sec. II Part C for alloy 625.

Figure 7 PMI Reading spot Cr 21.50, Mo 8.25, Ni 60.08, Nb 3.49, Fe 5.4

To further evaluate the properties of CRA clad material, mechanical, chemical and corrosion resistance properties. The clad coupon was sent to Testing laboratory which are PT Hi-Test Batam and Element Singapore.

Material Tensile Test

Tensile test was conducted by one longitudinal and one transverse tests specimen prepared by removing CRA layers. The acceptace criteria reference for X60 grade is YS: 415-565 MPa, TS: 520-760 MPa, % elongation as per API 5L Table H.2 and YS/TS Ratio ≤ 0.9. Figure 8 shows perform material tensile test at room and environment temperature in transverse orientation.

Figure 8 Tensile Test conducted at PT Hi-Test laboratory, perform at room and environment temperature in transverse orientation

The bend test carried out in accordance with ASME Section IX requirements shows in Figure 9. Transverse bend test specimens perpendicular to direction of weld bead, reference to ASME IX. The acceptance criteria for corrosion resistant weld overlay cladding, no open discontinuity exceeding 1.5mm measured in any direction in the cladding and no open discontinuity exceeding 3mm along the approximate weld interface

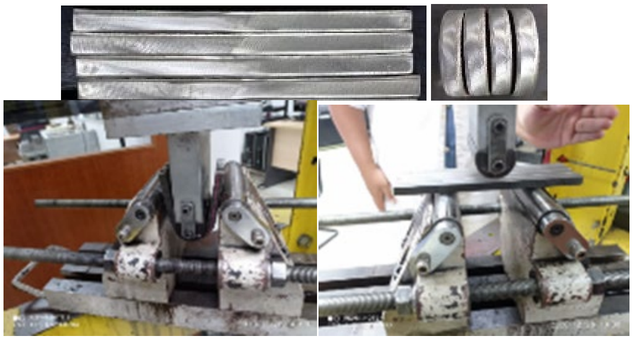

Figure 9 Side Bend Test conducted at PT Hi-Test laboratory - bending test perpendicular to the direction of welding at room temperature, test specimen size (9,27 + 3mm clad, thickness 10mm, bend angle 180° and former diameter 40mm.

Hardness Test

Two hardness test traverses as per API 5LD sec 7.13. Survey taken through CS and CRA weld overlay section. The total number of 3 specimens x 20 indentations each. The maximum hardness of carbon steel is 248 HV10 and HAZ location between carbon steel/alloy 625 is 250 HV10. Hardness in the alloy 625 layer shall not exceed 345 HV10. In figure 10 shows hardness test load test at 10 Kgf conducted at the laboratory.

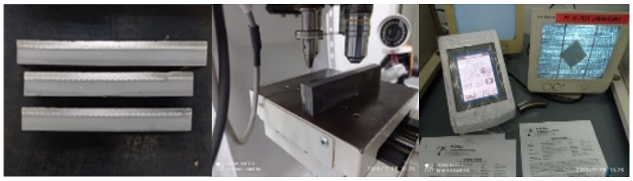

Figure 10 Hardness Number (HV) Load Test, 10Kgf (HV10) conducted at PT Hi-Test laboratory

Charpy Impact Test

The charpy impact V-notch test in Figure 11 was performed in accordance with ASTM A370. Three transverse specimens was taken from the pipe body (i.e., 3T). In any case, CRA weld overlay area shall be completely removed prior to testing. Test temperature at -20°C. Shear fracture area shall also checked and reported. The reference acceptance criteria 30 J (min. average value), 27 J (min. individual value), 85% (min. average shear) and 80% (min. individual shear).

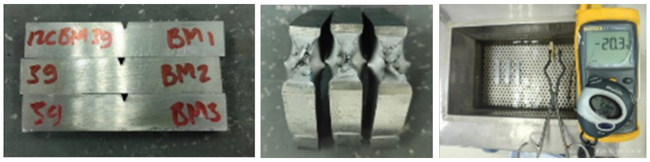

Figure 11 Charpy V-Notch Impact Test at transverse orientation conducted at PT Hi-Test laboratory

Chemical Analysis – Optical Emission Spectroscopy (OES) Method

In figure 12, chemical analysis (overlay) check made on sample taken from one test piece. The location of chemical analysis at distance of 1.5mm above fusion line as QW-462.5(a). Analysis performed using optical emission spectroscopy (OES). The cladding shall confirm to the chemical composition specified in ASME IIC SFA5.14 for UNS N06625 (ER NiCrMo-3) with the exception that maximum allowable iron content due to dilution of deposited weld metal shall be no more than 5%. PREN = %Cr + 3.3%Mo + 16%N shall be reported.

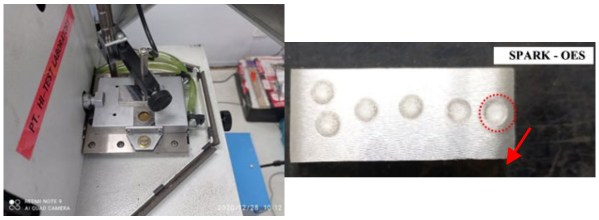

Figure 12 Chemical Analysis – Optical Emission Spectroscopy (OES) Method

Pitting Corrosion Test ASTM G48 Method A at 1mm, 2mm and 3mm CRA thickness

In Figure 13, pitting corrosion test was carried out on a CRA overlay specimen in accordance with ASTM G48-11 Method A specification. Corrosion test specimens was prepared by removing the backing carbon steel by milling or by other means and without machining the finished weld overlay surface. The thickness of the specimen machined approximately 1.0mm, 2.0mm and 3.0mm. The dimensions of the specimen shall be as recommended in ASTM G48 Method A are 75mm x 25mm and the sample was subjected to 72 hours (from 09:57 am on January 05, 2021 to 09:57 am on January 08, 2021) of total immersion in FeCl36H2O (ferric chloride hexahydrate) with pH value of 1.3. As per ASTM G48 paragraph 6.1, at a constant test temperature of 50±2°C. Pickling of the specimen with acid solution may be performed if required. For this purpose prior to perform corrosion test, the specimen is pickled and passivated for 24 hours. Examination result at 20x magnification was observed.

Figure 13 Pitting Corrosion Test G48 at PT. Hi-Test Laboratory (1mm, 2mm, 3mm specimen)

Corrosion Test ASTM G28 Method A at 1mm, 2mm and 3mm CRA thickness

In figure 14, corrosion test specimens prepared by removing the backing carbon steel by milling or by other means. The dimensions of the specimen as recommended on ASTM G28 Method A. Test duration is for 120 hours (from 09:32 am on January 06, 2021 to 09:32 am on January 11, 2021) in immersion with Ferric Sulphate solution at boiling test temperature (approx. 100 - 120°C). The surface of specimen was pickled before testing. The thickness of the specimen not less than 1mm, 2mm and 3mm and dimension: 25mm length x 25mm width. Metallographic examination is performed on unloaded G28 samples and subsequently performed micrographic photo at 50x magnification to verify that specimen shall not exhibits preferential attack on grain boundaries. The test was conducted on two different independent laboratory which is in PT Hi-Test (specimen of 1mm and 3mm CRA thickness) and Element Singapore (specimen of 2mm CRA thickness).

Figure 14 Corrosion Test G28 at PT. Hitest Laboratory and Element Singapore

6.0 RESULTS AND DISCUSSION

Table 7 shows tensile properties (both Yield and Ultimate strength) show no significant change after overlay process and within the acceptance criteria of API 5L X60.

Table 7. Tensile Test Result and Comparison

Tensile Test	Before clad*		After clad**	
	Longitudinal	Transverse	Longitudinal	Transverse
YS 0.5% MPa	493	464	545	483
UTS MPa	566	548	640	576
YS/UTS Ratio	0.87	0.85	0.85	0.84
E (%)	36	36	28	32

Note: *Value mentioned as originated from related MTC, **Value mentioned as tested after weld overlay (CRA clad portion was removed prior testing)

Tensile properties (both Yield and Ultimate strength) show no significant change after overlay process and within the acceptance criteria of API 5L X60.

Table 8 Bending Test (Perpendicular to the direction of welding)

Specimen No	Type of Bend	Observation	Result
SB 1	Side Bend	No discontinuities was observed	Accepted
SB 2	Side Bend	No discontinuities was observed	Accepted
SB 3	Side Bend	No discontinuities was observed	Accepted
SB 4	Side Bend	No discontinuities was observed	Accepted

Based on the specimen tested, Table 8 shows no discontinuities have been observed and show the clad material's ability to undergo bending deformation. Although the quantitative values associated with the tensile test will not be shown, the bend test will show both the weld's quality and its overall ductility.

Table 9 Hardness Test

Test Location	Before Clad*	After Clad**
	Average (HV10)	Average (HV10)
CS Outside Wall	181.3	183
CS Mid Wall	172.3	194
Weld Metal (CRA)	NA	229
HAZ	NA	217

Note: *Value mentioned as originated from related MTC, **Value mentioned as tested after weld overlay

Two hardness test specimens was performed as per API 5LD sec. 7.13. The survey taken through thickness of CS and CRA weld overlay section. Hardness testing performed according to the required location. The maximum hardness of the carbon steel for sour service is 248 HV10. The maximum hardness of alloy 625 layer shall not exceed 345 HV10. Table 9 results show all the values are within the acceptance criteria.

Table 10 Impact Test Result

Charpy Impact Test	Base Metal (API 5L X60)	
	Before clad*	After clad**
Specimen Size	7.5 x 10 x 55mm	7.5 x 10 x 55mm
Temperature	-20°C	-20°C
Value 1	249 J	287 J
Value 2	259 J	281 J
Value 3	248 J	282 J
Average	252 J	283 J

Note: *Value mentioned as originated from related MTC, ** Value mentioned as tested after weld overlay

In Table 10 results show all the values are within the acceptance criteria as per API5L

Chemical Analysis of CRA Layer

Chemical analysis of the overlay was performed on the sample taken from the test coupon sent to laboratory. Location of the chemical analysis at a distance of 1.5mm above the fusion line as per QW-462.5 (a) of ASME Section IX. The analysis was performed at the PT Hi-Test laboratory using optical emission spectroscopy (OES) and direct verification using the PMI method on the specimen's clad surface.

Table 11 Chemical Analysis Comparison of CRA Layer

Sample	Method	Sampling Location	% Element					PREN
			Ni	Cr	Fe	Mo	Nb	
Filler Wire	-	As per MTC	64.50	22.22	0.26	8.72	3.68	50.99
Clad Deposit	OES Analyser	1.5mm from Fusion Line	60.5	1,45	2.99	9.1	3.52	58.74
	XRF PMI	Clad surface	59.32	21.75	5.79	8.21	3.47	48.84

Note: PREN Calculation was made without Nitrogen element on the equation. PREN Calculation: PREN= %Cr + 3.3%Mo + 16%N. ASME Sec II Part C SFA 5.14 UNS N06625 with Fe = 5% Max.

The chemical analysis results were shown in Table 11 the elements are within the acceptance criteria of ASME Sec II Part C SFA 5.14 UNS N06625 (ER NiCrMo-3).

Table 12 Pitting Corrosion Results

G48-A Test	1st Test Coupon (1mm)	2nd Test Coupon (2mm)	3rd Test Coupon (3mm)
Test Temperature	50°C	50°C	50°C
Test Duration	72 Hours	72 Hours	72 Hours
Surface Area	4233.184 mm^2	4380.232 mm^2	4607.422mm^2
Weight Loss for sample	0 gr	0 gr	0 gr
Weight Loss per area	0 gr/m^2	0 gr/m^2	0 gr/m^2
Observation	No pitting observed at 20X mag	No pitting observed at 20X mag	No pitting observed at 20X mag

The pitting corrosion test results were found satisfactory without any weight loss after 72 hours immersion and no pitting was observed at 20X magnification as shown on Table 12.

The results macro photography before and after pitting corrosion test was taken and shown on below Figure 15 for specimen 1mm, 2mm and 3mm respectively.

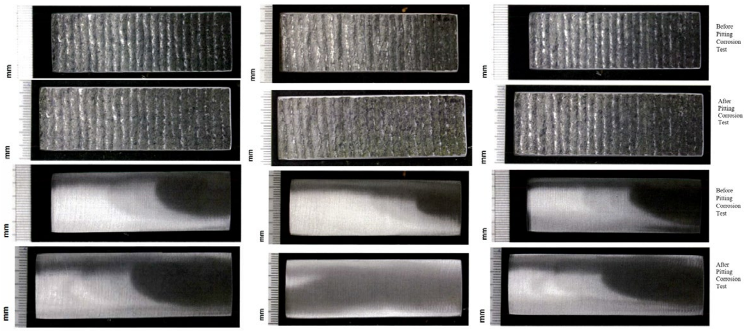

Figure 15 Macro-photography before and after Pitting Corrosion Test (1mm, 2mm, 3mm specimen)

Table 13 Intergranular Corrosion Test Results

ASTM G28-A Test	1st Test Coupon (1mm)	2nd Test Coupon (2mm)	3rd Test Coupon (3mm)
Test Temperature	Boiling	Boiling	Boiling
Duration of Test	120 hours	120 hours	120 hours
Surface Area	1432.12 mm^2	1456 mm^2	1632.81mm^2
Weight Loss	0.09 gram	0.0623 gram	0.0758 gram
Corrosion Rate	0.54 mmpy	0.37 mmpy	0.40 mmpy

The results above in Table 13 show that weld overlaid products provide pitting resistance and exhibit good intergranular corrosion resistance. The corrosion rate on alloy 625 weld overlay products is <0.914 mmpy as recommended by most Customers and common industrial standards. The results found that the corrosion rate is within the recommended criteria. In addition, the Intergranular Corrosion sample was validated by micro-examination shown in Figures 16, 17 and 18, which showed no intergranular surface attack.

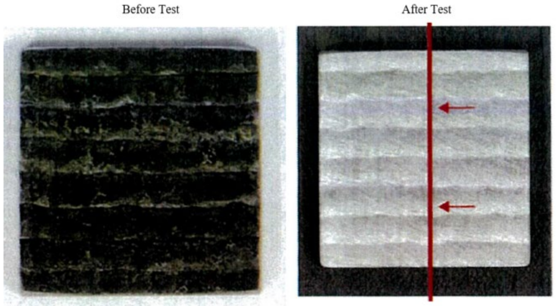

Figure 16 G28 – Before and after test photographs (red line indicates micro location)

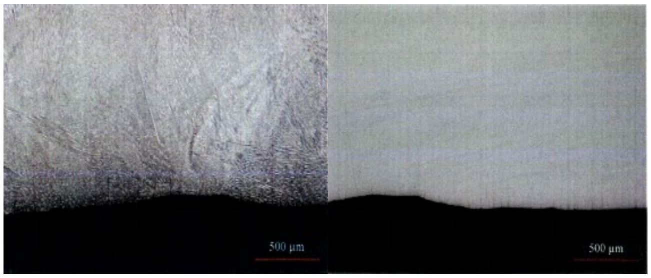

Figure 17 Micrograph as polished (left) and etched (right) shows no preferential attack at the overlay surfaced observed. Etchant: 10% Oxalic Acid, Electrolytic (Test at Element Singapore)

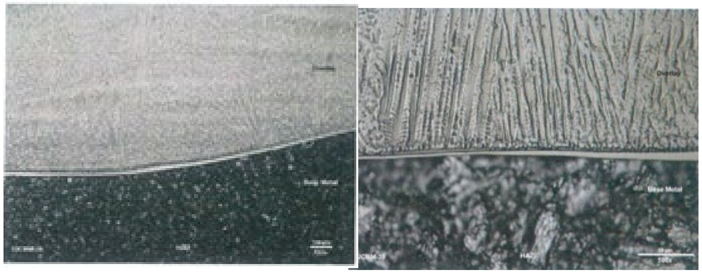

Figure 18 Micro examination in fusion line at 100x and 500x magnification

Macro Examination

The macro examination was taken through thickness, which showing each layer of weld overlay shows in Figure 19. Macro examination was performed in accordance with ASME Section IX. Two macro examination photos at 10x magnification. As observed, the total thickness of 1st layer and 2nd layer is approximately 3.7mm.

Figure 19 Macro 10x examination and photo

Economical Comparison

The data presented from Cladtek material historical cost database for comparison of Solid CRA and CRA clad piping components and standard use is specified mostly by Customer and industrial standards.

Table 14 and Table 16 below describe the benefits of weld overlay cladding outweigh solid duplex material and its advantages during fabrication of spooling

Table 14 Benefits of Weld Overlay Cladding outweigh Solid Duplex

Weld Overlay Clad	Solid Duplex 2205 or Super Duplex 2507
Lower Cost	Higher Cost
Faster Delivery	Longer Delivery
Better Mechanical Properties (from CS material) and Corrosion Resistance (from CRA)	Suitable for Corrosion Resistance
Higher Productivity in Fabrication in the sense of material treatment	Higher Maintenance in Fabrication in the sense of material treatment
No Minimum Order Quantity (MOQ)	Minimum Order Quantity (MOQ) for mill production

Material Properties

Weld Overlay Clad Pipe commonly from carbon or low alloy steel (LAS) weld overlay cladded with Corrosion Resistant Alloy (CRA), e.g., API 5L X60 weld overlay cladded with nickel alloy 625; CS/LAS high mechanical resistance and alloy 625 high corrosion resistance (same as solid material) in different media (e.g., sour service); The high flexibility of substrate (base material) with different mechanical properties; CS/LAS low in manufacturing cost; A better choice for HPHT application (strength/thickness ratio). Duplex and Super Duplex Stainless Steel Pipe properties are: Higher corrosion resistance and mechanical properties than austenitic stainless steel; High manufacturing cost. Table 15 compares the min temperature, mechanical properties, and pitting resistance of solid CRA and carbon steel pipe clad with alloy 625. The comparison table demonstrates the suitability of alloy CRA clad materials in a corrosive environment with a high pitting resistance equivalent greater than 50.

Table 15 Material Properties Comparison regenerated table from ASME B31.3 Ed. 2014 [7]

Material type	Min. Temp. (°C)*	Mechanical properties*		Corrosion resistance		
		YS (ksi)	UTS (ksi)	CCT (°C)	CPT (°C)	PREN
Duplex stainless steel	-51	70	95	20	40	33 - 38
Super duplex stainless steel	-51	80	116	35	75	40 - 43
API 5L X65 + UNS N06625	-29	65	77	35	> 85	> 50
API 5L X80 + UNS N06625	-29	80	90	35	> 85	> 50
ASTM A333 Gr.8 + UNS N06625	-195	75	100	35	> 85	> 50

*ASME B31.3 Ed.2014

Table 16 Fabrication Spooling Comparison

	Weld overlay cladded pipe	Duplex stainless steel pipe
Dedicated area	Not required	Required
Dedicated tools	CRA only	Required
Contamination risk	Low risk	High risk
Heat input control	Normal control	Tight control
Interpass temperature control	200 °C, max.	100 °C, max.
Welding	Readily	Complex
Productivity	Higher	Lower

Table 17 Case 1: Duplex 8”x27.76mm VS X65 8”x30.67mm + 3mm Alloy 625

Category	Duplex (US$/unit)	Clad (US$/unit)	Difference (%)
Pipe	1,390.00	1,084.00	-22,00%
Flange	3,988.00	1,832.00	-54,05%
Elbow	4,904.00	1,452.00	-70,39%

Table 18 Case 2: Duplex 10”x30.16mm VS X65 10”x33.32mm + 3mm Alloy 625

Category	Duplex (US$/unit)	Clad (US$/unit)	Difference (%)
Pipe	1,917.00	1,421.00	-25,89%
Flange	7,975.00	3,100.00	-61,13%
Elbow	10,414.00	2,658.00	-74,48%

Table 17 and 18 shows the comparison data from Cladtek, the consideration made to material data at pressure rating 2500 and the standard wall thickness piping. CRA clad materials are better in terms of Corrosion Resistance and mechanical properties comparing with the solid duplex; For severe environments (High Temperature High Pressure), CRA clad products are the best choice. CRA clad materials are higher productivity for spooling. CRA clad materials are saving around 40-50% for materials with high thickness are more faster lead time as piping material and cladding manufacturing process.

7.0 CONCLUSION

One application of CRA clad by weld overlay method is in the wellhead piping system in geothermal power plant exposed in the highly corrosive environment. The weld overlay cladding is performed to increase the components' life and replace an expensive corrosion-resistant solid material. The CRA clad material's performance will be strongly affected when the surface is exposed to acidic conditions. A correct material selection with suitable mechanical, chemical and corrosion resistance properties is required to assess properly. The result of the qualification approach used in the evaluation of alloy 625 clad into carbon steel X60 grade has observed and concluded as follows:

Most of the weld overlay tests done provide valuable information on the evaluation of alloy 625 and the welding method used. The non-destructive tests performed after cladding is effective and give a direct result, although in fully automatic processes like TIG welding would not expect any fusion problems as long as correct welding parameters and procedures are followed. In the HTHP service condition, the carbon steel substrate material withstands the pressure and the overlay material counter the corrosive environment.

To evaluate the suitability of alloy 625 in defined geothermal conditions, the coupon sent to an independent laboratory for further tests by performing mechanical, chemical and corrosion test. The tensile properties (both Yield and Ultimate strength) show no significant change after overlay. The tensile properties are suitable for high pressure in accordance with the X60 grade design. Side bend test was performed perpendicular to the direction of welding and found no discontinuities on CS + CRA interface. The side bend test result shows that the clad material's ability to withstand undergo bending deformation. Although the quantitative values associated with the tensile test will not be shown, the bend test shows both the weld's quality and its overall ductility.

In ASME IX, heat input for weld overlay cladding is an essential variable controlled with low heat input and electronically controlled in TIG welding, which provides lower dilution (Fe<5%). This was validated by chemical analysis using the OES method at 1.5mm from the fusion line and revalidated by the XRF method (PMI) at the final clad surface.

The CRA material grade alloy 625 used in the test sustained any pitting corrosion attack after 72 hours of exposure to the acid solution with a pH of 1.3 value at the temperature of 50 °C without any weight loss. This test solution is more acidic than the type of geothermal fluid with 3-4 pH value.

The corrosion rate on the 625 weld overlay product is less than 0.914 mmpy as recommended by most Costumer and industry standards, which has stringent criteria in the material selection process. This experiment achieved 0.40 mmpy at 3mm thickness. The results show that CRA clad products can prolong the service life of approximately 20 years.

CRA clad's cost versus solid alloy was compared economically and the cost savings can be made up to 40-50% in the case study presented with high thickness and size variation. It could be estimated that the use of CRA clad pipe components for this thickness would result in about 50% cost savings compared to solid material in terms of raw material cost and manufacturing or manufacturing spool.

Acknowledgement

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