Journal of Ocean, Mechanical and Aerospace
-Science and Engineering-
30th July 2024. Vol.68 No.2

July 30, 2024

Enhancing ASTM B424 UNS N08825 Long Seam Weld Liner Material with Annealing Quenching Techniques in the Cladding Process on the Surface of Steel Pipes

Yunasri[a], Fardin Hasibuan[a*], Arif Rahman Hakim[a] and Nugroho Pratomo Ariyanto[b]

[a)] *Mechanical Engineering Study Program, Faculty of Engineering, Universitas Riau Kepulauan, Batam, 29422, Indonesia*
[b)] *Mechanical Engineering Department, Politeknik Negeri Batam, Batam, 29641, Indonesia*

*Corresponding author: fardin.hasibuan123456@gmail.com

Paper History

Received: 15-June-2024
Received in revised form: 15-July-2024
Accepted: 30-July-2024

ABSTRACT

Cladding methods in manufacturing corrosion-resistant pipes are crucial for industries such as oil and gas, chemical plants, and pressure vessel manufacturing. This study focuses on ASTM B424 UNS N08825, a Corrosion-Resistant Alloy (CRA) to be used as the surface layer for steel pipes. The cladding method involves forming CRA sheets into longitudinal pipes, welding the joints, annealing, and rapid cooling before high process expansion to the surface layer of the steel pipes. At a temperature of 930-990°C, the annealing process aims to reduce stress and improve material properties, followed by rapid cooling to stabilize the microstructure. Various tests were conducted on the CRA liner pipes with or without annealing and quenching, including tensile testing, hardness testing, chemical composition analysis, and microstructure examination. The results showed that the material's ultimate tensile strength and hardness significantly increased after the treatment, with better uniformity in the microstructure. This study concludes that annealing and rapid cooling enhance the mechanical properties and stability of ASTM B424 UNS N08825, allowing the cladding process on steel pipe surfaces to be performed flawlessly and making it suitable for high-performance applications in corrosive environments.

KEYWORDS: *Enhancing, ASTM B424 UNS N08825, Annealing, Quenching, Cladding.*

1.0 INTRODUCTION

In engineering industries such as oil and gas, chemical plants, and pressure vessel manufacturing, the pipe specifications required for operations vary depending on the specific application, including pressure, temperature, type of fluid transported, operating environment (onshore or offshore), and industrial safety standards [1]. Oil and gas have become indispensable commodities daily, and their demand is rising with population growth. Most oil and gas reservoirs exhibit high levels of corrosion, posing a significant challenge for producers due to the associated lower cost. The operator assumes the financial burdens if these pipelines are temporarily closed for maintenance or replacement due to corrosion. As per the World Corrosion Organization, corrosion incurs a financial burden of $2.2 trillion on the global economy, which is approximately 3% of the world's Gross Domestic Product (GDP) [2].

Corrosion is a natural process of gradual destruction of materials in the presence of a particular environment [3], [4], [5]. Corrosive coatings, primarily polymers, can be applied to prevent corrosion in pipelines. However, polymer coatings have certain limitations regarding their suitability for different operating environments. Polymer coatings such as polyethylene (PE), polypropylene (PP), epoxy, and fusion-bonded epoxy (FBE) are not suitable for applications involving elevated temperatures and pressures. Furthermore, these materials offer only a restricted resistance level to sulfur, Amines, Chloride, and oxygen. This is particularly significant because oil and gas fluids contain elevated levels of H2S, CO2, and solid particles such as sodium chloride, potassium chloride, filth, and grease. H2S, CO2, and chlorides have caused coracle damage. Selecting a suitable line pipe is essential in a demanding setting characterized by elevated temperatures, increased pressure, and a corrosive atmosphere [6]. The high-strength line pipe steel is already in use for higher pressure but has limited corrosion resistance. To combat the corrosion, the Clad line pipe is one of the best economical solutions for pipeline operators. One of the technologies used in manufacturing corrosion-resistant pipes is the cladding method, where carbon steel pipes undergo a

ISOMAse
International Society of Ocean, Mechanical and Aerospace Scientists and Engineers

Journal of Ocean, Mechanical and Aerospace
-Science and Engineering-
30th July 2024. Vol.68 No.2

cladding process using materials resistant to corrosion and oxidation [1], [6], [7], [8].

Cladding on steel pipes became the primary solution provider for the corrosion problem as advanced manufacturing techniques developed [9]. Since cladding is an overlay process, it provides supplementary tensile and corrosion resistance strength to the carbon steel substrate against welding. Since the bonding method has to play an essential role in cladding efficiency, it acts as a barrier separating the substrate and the environment around it, providing sacrificial protection against galvanic corrosion. Nevertheless, cladding has its limitations, such that embrittlement on account of hydrogen is aided after the formation into a pipe, leading to defects like cracking and dis-bonding [10]. Concerning the Corrosion Resistant Alloys (CRA) materials, aluminum and chromium have made their mark as anticorrosion agents. Corrosion-resistant alloys are metals specifically designed to withstand deterioration caused by oxidation or various chemical reactions. The most frequently utilized corrosion-resistant metals are suitable for mild to moderate levels of corrosion resistance [11]. They are cladding deposits of surface material to the base metal by welding fusion or other mechanical processes [12]. This can be accomplished with different techniques, such as roll bonding, explosion bonding, or powder metallurgy. Pressure and temperature play essential roles in the deposition when using these cladding methods. The process can be used for pipes, tubes, metal sheets, or equipment with an ideal metal surface. The cladding process aims to Improve the component's temperature and corrosion resistance, Improve the component's stress and impact resistance, and Prevent the wear and tear of the component [13].

Cladding adds depositing surface material to a base metal using fusion welding techniques or other mechanical methods. Various techniques can be employed, such as roll bonding, explosion bonding, or powder metallurgy [14]. Pressure and temperature play crucial roles in the deposition process when using cladding methods. This process can be applied to various pipes, tubes, metal sheets, or equipment requiring a desired metal surface. The primary purpose of the cladding process is to enhance the temperature and corrosion resistance of components, improve resistance to stress and impact, and prevent component wear.

ASTM B424 UNS N08825 is a commonly used material for cladding. It is a nickel-iron-chromium austenitic alloy with the addition of molybdenum, copper, and titanium. It is widely recognized for its exceptional ability to withstand both oxidizing and reducing conditions. The presence of titanium in the alloy ensures its high stability against sensitization. When the alloy is subjected to temperatures that can sensitize unstable stainless steel, Incoloy 825 products demonstrate exceptional resistance to intergranular assaults upon exposure [15]. This material is used to clad carbon steel pipes in the oil and gas industry. The manufacturing process of liner pipe material ASTM B424 UNS N08825 is used as a cladding material on carbon pipes. This material is corrosion-resistant and wear-resistant, making it widely used in oil and gas production drilling.

The manufacturing process for CRA liner pipe ASTM B424 UNS N08825 is as follows, coils of this material are formed into longitudinal pipes. The longitudinal pipe manufacturing process involves several stages broadly divided into three parts forming, welding, testing, and inspection. These coils are uncoiled and cut into smaller strips according to the desired size. The cut strips undergo an inspection to ensure there are no defects or inconsistencies. After passing the inspection, the strips are crimped to form the inner lining of the pipe. These crimped strips are then subjected to cold forming, where they are shaped into pipes. The longitudinal seams of these pipes are welded, and this weld is tested using liquid penetrant testing to detect any defects. Following this, the thickness of the CRA liner pipe is checked to ensure it meets the required specifications. A visual inspection is conducted on the CRA liner pipes to identify any visible defects. The pipes are then calibrated to ensure their dimensions match the desired specifications. The ends of the CRA liner pipes are cut to achieve the correct length and a smooth surface. Next, the pipes undergo annealing, a heat treatment process that relieves internal stresses and enhances the mechanical properties of the material. After annealing, the pipes are quenched, rapidly cooled to harden the material. Subsequently, the pipes are subjected to a final dimensional check (FDC) and a final visual inspection (FVI) to ensure they meet all the required specifications. Pipes that do not pass this inspection are repaired and re-inspected. If they cannot be repaired, they are rejected. Pipes that pass the final inspection are accepted and proceed to the reporting stage, where all inspection and testing results are documented. This thorough process ensures that the produced CRA pipes meet stringent quality standards and are ready for use in applications requiring high corrosion resistance.

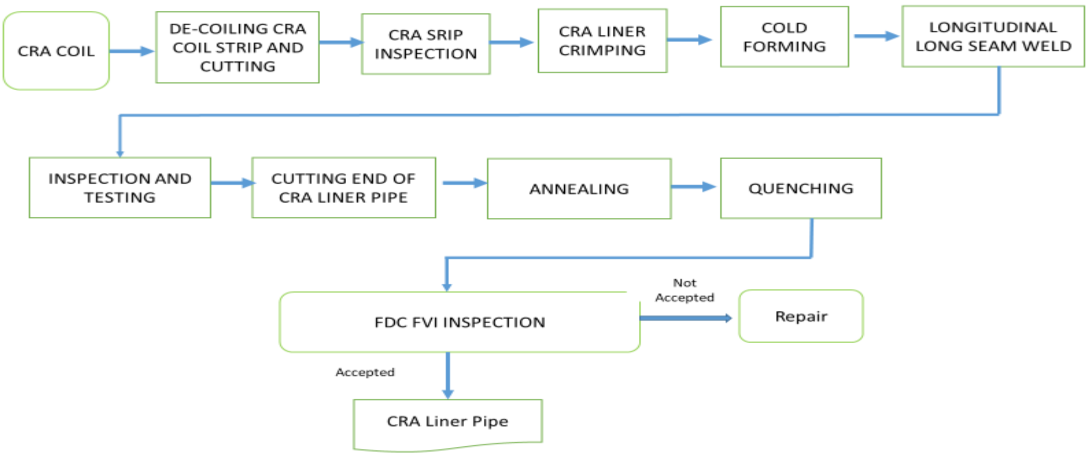

Figure 1: The process of forming CRA liner pipe from CRA coil.

JOMAse | Received: 15-June-2024 | Accepted: 30-July-2024 | [(68) 2: 75-81]
Published by International Society of Ocean, Mechanical and Aerospace Scientists and Engineers, www.isomase.org., ISSN: 2354-7065 & e-ISSN: 2527-6085

After forming the pipe into CRA liner pipe, once the CRA liner pipe meets the established standards, it will follow to next process. One of the most critical steps in this process is the hydroforming stage, where a water pressure of 150 bar is used to press the CRA liner pipe against the surface of the steel pipe so that the outer side of the liner pipe comes into contact (bonds) with the inner side of the carbon pipe (expansion process). The high-pressure water pressing process can cause damage or cracking in the seam weld area or at base material of the liner pipe. One stage in the manufacturing process of CRA liner pipes involves cold forming and longitudinal long seam welding, which can impact the material's properties and strength.

Cold working refers to the deformation of metals at room temperature through methods such as cold rolling, which results in the flattening and elongation of grains. This deformation causes complex movements within and between the grains, distorting and disrupting the metal's crystalline structure. Residual stress in welded structures can cause considerable issues. Typically, the maximum stress equals the yield strength of the weakest material in the weld joint. Such stress can lead to distortion, especially if the component undergoes further processing after welding. Moreover, residual stress can diminish the fracture toughness of the welded structure under certain conditions. To mitigate these problems, a stress relief process is employed. This involves heating the material below the lower transformation temperature, where new grain growth can begin [16]. To reduce the potential damage or cracking in this welded area, the liner pipe undergoes an annealing treatment and followed by quenching treatment before cladding onto the carbon pipe. The annealing process is used to normalize and relieve stress concentration in the welded area, making it safe for the expansion process during cladding onto the carbon steel.

Annealing is performed to eliminate residual stress in the longitudinal CRA pipe [17]. Annealing is a heat treatment process for metals or alloys. They are heated to a specific predetermined temperature and held at that temperature for a particular duration; this process aims to improve flexibility. Heat treatments are commonly employed in metal processing to restore lost elasticity due to forging or other working methods. Full annealing is typically performed to achieve the desired hardness level in specific parts, such as molds used in machine tooling industries. Additionally, annealing processes can also be used to relieve internal stresses within the material [18], [19]. The temperature used in annealing varies depending on the type of metal or alloy and the desired properties but should be within a range that prevents undesirable crystal growth [20].

Quenching is a rapid cooling process applied to metals to return them to room temperature while avoiding significant microstructural changes through diffusion, which can occur if the material is cooled through lower temperatures. Quenching can be performed using various liquid or air media and other materials that can rapidly absorb heat. Commonly used media include freshwater, saltwater, forced air convection, oil, and special polymers. When using liquid media like water, it is crucial to prevent the formation of vapor pockets that can disrupt the hardening process with subsequent air cooling once these pockets dissipate. While water is adequate for achieving maximum hardness, there is a small risk of distortion and minor cracking. Quenching applied to nickel materials is beneficial for metal hardening to enhance nickel materials' mechanical properties and wear resistance [5]. Phase transformation in some alloys, rapid cooling can induce specific phase transformations, but in Incoloy 825, its austenitic structure remains stable and does not undergo a martensitic transformation. Thus, grain size typically remains unchanged.

This paper presents research examining enhancement for manufacturing corrosion-resistant pipes by employing ASTM B424 UNS N08825 as the surface layer on steel pipes. The research introduces an annealing technique at temperatures between 930-990°C, followed by rapid cooling, which significantly improves the material properties of the corrosion-resistant alloy. Unlike traditional methods, this approach enhances the ultimate tensile strength and hardness and achieves superior microstructural uniformity. The findings demonstrate that the novel cladding process can be flawlessly integrated into steel pipe surfaces, substantially improving mechanical properties and stability and making it ideal for use in harsh and corrosive environments.

2.0 METHOD

2.1 Experimental Methods Annealing and Quenching Treatment

The CRA liner pipe undergoes annealing and quenching treatment. The liner pipe moves on a traveling movement system, entering the induction coil furnace at an initial temperature of 28 degrees Celsius. It is then heated in the furnace to a minimum of 930 and a maximum of 990 degrees Celsius. Upon exiting the furnace, the pipe moves at a minimum travel speed of 350 and a maximum of 450 mm/minute, with a heating duration inside the furnace of 60-90 seconds.

After exiting the furnace, the pipe is cooled by air and then enters a cooling chamber where it is sprayed with water. The temperature of the CRA liner upon entering the cooling chamber is 225.8 degrees Celsius, and the water temperature is 23 degrees Celsius. The pipe exits the cooling chamber at a temperature of 41.5 degrees Celsius. Figure 2 shows the process annealing and quenching.

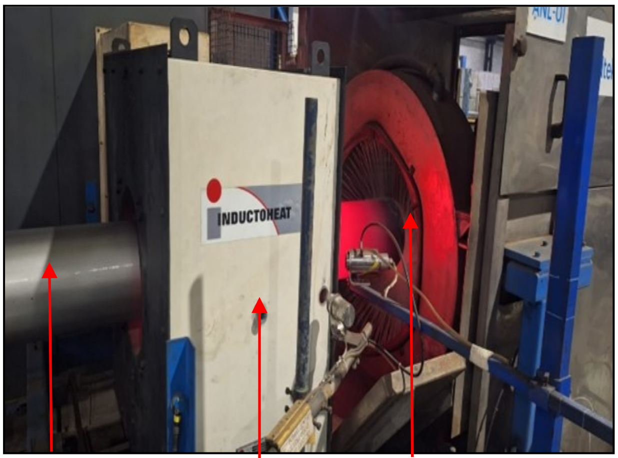

Figure 2: CRA Liner annealing and quenching process

JOMAse | Received: 15-June-2024 | Accepted: 30-July-2024 | [(68) 2: 75-81]
Published by International Society of Ocean, Mechanical and Aerospace Scientists and Engineers, www.isomase.org., ISSN: 2354-7065 & e-ISSN: 2527-6085

Journal of Ocean, Mechanical and Aerospace
-Science and Engineering-
30th July 2024. Vol.68 No.2

July 30, 2024

Figure 3a: Temperature inlet coil induction furnace

Figure 4a: Temperature inlet quenching chamber

Figure 3b: Temperature outlet coil induction furnace

Figure 4b: Temperature outlet quenching chamber

The parameters for the annealing and quenching temperature processes are as follows:

1. The temperature of the CRA Liner entering and outlet the coil induction furnace as can be seen in Figure 3a and 3b.
2. The temperature of the CRA Liner entering and outlet the quenching chamber as depicted in Figure 4a and 4b.

2.2 Material, Equipment and Tool

Forming sample CRA liner pipe with an inner diameter of 250 mm, a wall thickness 3 mm, and length 6 meters. requires several equipment and tools. The materials, equipment and tools needed are listed in Table 1 – 3.

Table 1: Material sample

No	Material	Specification
1	Base material	Corrosion Resistance Alloy (CRA) Material ASTM B424 UNS N08825
2	Filler	ERNICRMO-3 UNS N06625

Table 2: Equipment specification

No	Equipment	Specification
1	Cutting CRA equipment	Production by Shung-Dar
2	Crimping equipment	Production by Cladtek
3	Cold Forming equipment	Production by Scalen Australia, Model No. FX 6S700, Serial No. 1074-6472-511
4	Plasma Arc Welding	Production by Meta Vision System, Type Smart Laser Probe
5	Annealing equipment	Production by Inductoheat Melbourne Australia, S/N C1450, Type No VIP-800-1, Input 1025kVA, 1350 A, 480 V, Output 800 kW, 1600 V
6	Quenching equipment	Production by Sondex Australia Pty.Ltd, Plate Heat Exchanger Type S211G1D, Maximum Working Pressure 8 Bar, Working Temperature Minimum 0^0C, Working Temperature Maximum 125^0C

JOMAse | Received: 15-June-2024 | Accepted: 30-July-2024 | [(68) 2: 75-81]
Published by International Society of Ocean, Mechanical and Aerospace Scientists and Engineers, www.isomase.org., ISSN: 2354-7065 & e-ISSN: 2527-6085

Table 3: Tool specification

No	Tool	Specification
1	Tensile Test	Instron Universal Testing Machine, S/N 600DXR9024 model 600DX-C3A-G7F with transverse sample orientation
2	Guided Bend Test	A motor pump bend test machine, serial no: HT-TM 00, model no: PUJ120E
3	Hardness Test	Zwick Roell Hardness Testing Machine, Model Dura Scan 70 G5, S/N: DS251917, with a Vickers Hardness Test type (HV) and a load test of 10 kgf.
4	Chemical Composition Analysis	ALR 3460 Metal Analyzer
5	Micro Examination	Optical microscope Nikon Eclipse MA 200 and type etchant solutions is Oxalic Acid 10 %

3. RESULT

Results of testing after annealing and quenching process comparation without annealing and quenching process.

3.1. Ultimate Tensile and Bending Test

Sample tests were conducted on samples containing weld joints and base material for both samples. The tests included tensile testing and bending tests. Results of the ultimate tensile test and bending test of the sample are shown in the Table 4.

Table 4: Result tensile and bending test

No	Test Criteria	Without annealing and quenching	With annealing and quenching
1	Tensile Test:		
	Ultimate Tensile Strength	596 MPa (location failure base material)	618 MPa (location failure base material)
2	Bending Test:		
	Face Bend	Accepted	Accepted

The ultimate tensile strength without annealing and quenching is 596 MPa, and the ultimate tensile strength with annealing and quenching is 618 MPa. This means the ultimate tensile strength with annealing and quenching is greater by 22 MPa or increased by 3.69% compared to the material that did not undergo annealing and quenching. The bending test results for the material, both without annealing and quenching and with annealing and quenching, are acceptable, or neither of them failed.

3.2. Hardness Test

Hardness testing was carried out at several points, precisely the base material, HAZ (Heat-Affected Zone), and the weld area. The number of points where hardness was checked totalled 13 points.. Figure 5 shows the hardness test points on both samples.

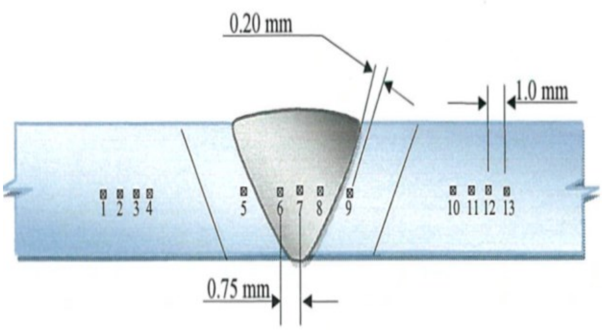

Figure 5: Hardness test location.

The hardness test used the Vickers Hardness Number (HV) test load applied10 kgf. The hardness test results for the material, both without annealing and quenching and with annealing and quenching, are shown in Table 5.

Table 5: Result Vickers Hardness Number

Test Location	Vickers Hardness Number (HV) Test Load Applied, 10 kgf	
	Without Annealing and Quenching	With Annealing and Quenching
Base Metal		
1	166	190
2	174	182
3	177	194
4	174	183
HAZ		
5	178	195
Weld Metal		
6	193	211
7	190	213
8	188	203
HAZ		
9	181	187
Base Metal		
10	178	208
11	168	199
12	168	201
13	180	193

JOMAse | Received: 15-June-2024 | Accepted: 30-July-2024 | [(68) 2: 75-81]
Published by International Society of Ocean, Mechanical and Aerospace Scientists and Engineers, www.isomase.org., ISSN: 2354-7065 & e-ISSN: 2527-6085

Journal of Ocean, Mechanical and Aerospace
-Science and Engineering-
30th July 2024. Vol.68 No.2

The hardness at all points increased after the annealing and quenching process. The most significant increase was at point 12 (base metal), with a hardness increase of 33 points, or 19.64%, compared to the material that did not undergo annealing and quenching

3.3 Chemical Composition

The chemical analysis of the CRA Liner with the following composition (%), it can be seen in Table 6.

Table 6: Chemical Composition CRA Liner

Element	Percentage (by Weight)
C	0.04
Mn	0.05
P	0.0003
S	0.0004
Si	0.06
Ni	62.37
Cr	21.81
Mo	8.19
Fe	3.76
Ta	0.02
Al	0.21
Ti	0.26
Co	0.03
Nb	3.12
N	0.01

It can be seen that the largest composition is Nickel (62.37%), Chromium (21.81%), and Molybdenum (8.19%), with a carbon content of 0.04%. The presence of carbon, chromium, and molybdenum in this material during the annealing process can cause precipitation and redistribution of existing carbides. Precipitation of secondary phases such as gamma prime (γ') or gamma double prime (γ'') may occur or change shape. This can enhance or alter the mechanical properties depending on the distribution and size of these precipitations [21].

Nickel (Ni) and Chromium (Cr) elements will maintain the stability of the austenitic phase at annealing temperatures, ensuring corrosion resistance and strength at high temperatures [22]. Molybdenum (Mo) will help improve high-temperature strength and corrosion resistance and may also participate in carbide formation. Aluminum (Al) and Titanium (Ti) play crucial roles in forming γ' precipitates, enhancing strength. Annealing at this temperature may cause re-precipitation or refinement of this phase. Niobium contributes to forming γ'' precipitates, providing strength at intermediate to high temperatures. Annealing may lead to changes in the size and distribution of these precipitates.

3.4. Micro Examination and Photo

The microstructure CRA Liner with and without annealing and quenching was investigated by metallographic analysis. Figure 6 shows the grain size and grain distribution without annealing and quenching. Figure 7 shows the grain size and grain distribution with annealing and quenching. The grain size is more uniform after the annealing and quenching process than without annealing and quenching.

4. DISCUSSION

4.1. Microstructure

The micro-structural evolution process during plastic deformation is very complex and involves various mechanisms such as dislocation slip, grain refinement, transformation induced plasticity, and twinning, which can affect the grains to a certain extent. Microscope was used to understand the microstructure of the nickel alloy after cold rolling, annealing, and quenching. A more uniform grain size is observed more frequently in the material that has undergone annealing and quenching processes compared to the process without annealing and quenching, with grain sizes ranging between 50-70 µm.

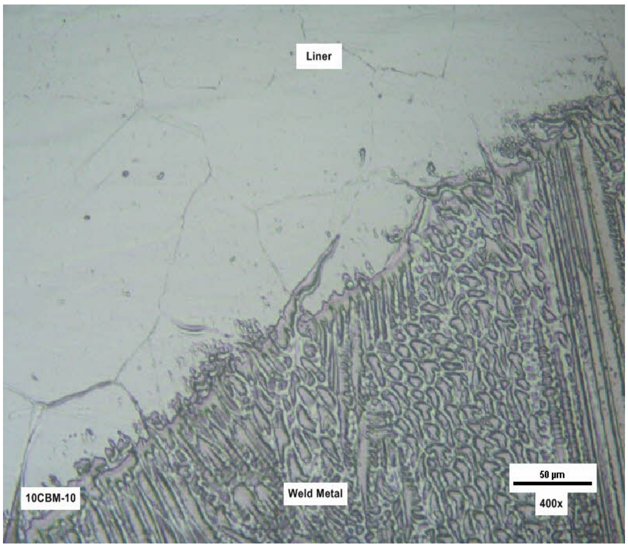

Figure 6: Microstructure without annealing and quenching

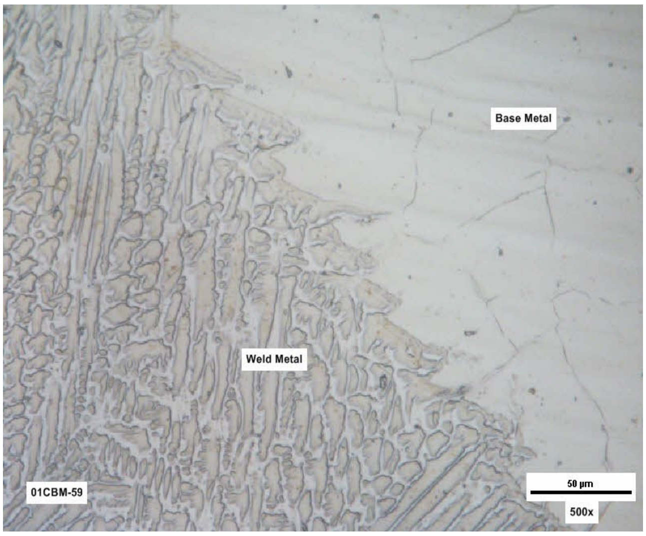

Figure 7: Microstructure with annealing and quenching.

4.2. Strengthening Mechanisms

The interplay of various dislocations, grain boundaries, twin boundaries, and phase transitions dictates the enhancement of metals' strength. The interaction between dislocations and grain boundaries gives rise to a far-reaching internal stress field called back stress. In alloys with a uniform microstructure, the grain size is reduced, which results in increased grain boundaries and dislocations. The presence of grain boundaries hinders the movement of dislocations, leading to a higher dislocation density and strain hardening. The annealing and

JOMAse | Received: 15-June-2024 | Accepted: 30-July-2024 | [(68) 2: 75-81]
Published by International Society of Ocean, Mechanical and Aerospace Scientists and Engineers, www.isomase.org., ISSN: 2354-7065 & e-ISSN: 2527-6085

quenching process applied to the ASTM B424 UNS N08825 material shows that the ultimate tensile strength increased by 3.69%, and the hardness increased by 3.31% to 19.64% compared to the material without the annealing and quenching process.

5. CONCLUSION

In this study, the material properties of material ASTM B424 UNS N08825 Long Seam Weld Liner were introduced by adjusting the annealing and quenching; this considerably improved the tensile properties, hardness, and stability of the as-received ASTM B424 UNS N08825. The strength of the material after annealing and quenching process is higher than that of material without annealing and quenching. The hardness in the weld area and the HAZ after the annealing and quenching process is higher compared to the material without annealing and quenching. The CRA liner that has undergone annealing and quenching positively impacts the surface cladding process of the steel pipe with this material, providing high strength, hardness, and stability. As a result, the cladding process can proceed without failure and has high corrosion resistance.

REFERENCES

[1] A. Subhan, A. Zahoor, and A.-H. I. Mourad, "Advances in manufacturing techniques of cladding steel pipes using corrosion-resistant alloy material for offshore oil and gas pipelines," in 2022 Advances in Science and Engineering Technology International Conferences (ASET), 2022, pp. 1–6. doi: 10.1109/ASET53988.2022.9734847.

[2] World Corrosion Organization, "Corrosion Costs and the Future," https://corrosion.org/Corrosion+Resources/Publications.html. Accessed on 30 June 2024

[3] S. Feng et al., "New insight of the enhanced oxidation resistance of T91 steel in 450 °C liquid lead-bismuth eutectic by adding Al and Si element," J Mater Sci Technol, vol. 204, pp. 29–46, 2025, doi: https://doi.org/10.1016/j.jmst.2024.03.033.

[4] W. Sun, Y. Lv, J. Gao, Q. Feng, B. Jia, and F. Ma, "Highly conductive and corrosion-resistant NbN coatings on Ti bipolar plate for proton exchange membrane water electrolysis," J Mater Sci Technol, vol. 210, pp. 86–96, 2025, doi: https://doi.org/10.1016/j.jmst.2024.05.038.

[5] S. Ma, X. Yang, L. Fu, and A. Shan, "Achieving High Strength-Ductility Synergy in Nickel Aluminum Bronze Alloy via a Quenching-Aging-Tempering Heat Treatment," Mater Lett, vol. 333, p. 133661, Jun. 2022, doi: 10.1016/j.matlet.2022.133661.

[6] K. Kishore, "Clad Linepipe to combat the Corrosion in Pipelines," Int J Res Appl Sci Eng Technol, vol. 6, no. 3, pp. 50–54, Mar. 2018, doi: 10.22214/ijraset.2018.3008.

[7] API MONOGRAM PROGRAM, "CRA Clad or Lined Steel Pipe," Sep. 2015. Accessed: Jun. 30, 2024. [Online]. Available: https://www.api.org/~/media/files/publications/whats%20new/5ld_e4%20pa.pdf.

[8] M. Brennan and R. Gassmann, "Laser Cladding of Nickel and Iron Base Alloys on Boiler Waterwall Panels and Tubes," Corrosion, 2000, [Online]. Available: https://api.semanticscholar.org/CorpusID:136712552, accessed on 25 June 2024

[9] H. Ilstad, H. Nes, and G. Endal, Strengthening Effect From Steel Pipe Cladding in Pure Bending. 2006. doi: 10.1115/OMAE2006-92524.

[10] L. Jemblie, V. Olden, P. Mainçon, and O. M. Akselsen, "Cohesive zone modelling of hydrogen induced cracking on the interface of clad steel pipes," Int J Hydrogen Energy, vol. 42, no. 47, pp. 28622–28634, 2017, doi: https://doi.org/10.1016/j.ijhydene.2017.09.051.

[11] Corrosion Resistant Alloys, "What Are Corrosion Resistant Alloys?," https://www.cralloys.com/portfolio/what-are-cras/. Accessed on 30 June 2024

[12] A. M. Inc. Engineering Department, "What Is the Difference Between Cladding and Overlay?", accessed on 27 June 2024

[13] T. Han, K. Zhou, Z. Chen, and Y. Gao, "Research Progress on Laser Cladding Alloying and Composite Processing of Steel Materials," Metals, vol. 12, no. 12. MDPI, Dec. 01, 2022. doi: 10.3390/met12122055.

[14] M. K. Saha and S. Das, "A Review on Different Cladding Techniques Employed to Resist Corrosion," Journal of the Association of Engineers, India, vol. 86, no. 1–2, p. 51, Jun. 2016, doi: 10.22485/jaei/2016/v86/i1-2/119847.

[15] Steel Tube India, "Incoloy 825 Plate," https://www.steeltubesindia.net/incoloy-825-plate-sheet.html. Accessed on 30 June 2024

[16] L. F. Jeffus, Welding and metal fabrication. Delmar, 2012.

[17] P. Trihutomo, "Pengaruh Proses Annealing Pada Hasil Pengelasan Terhadap Sifat Mekanik Baja Karbon Rendah," 2014.

[18] L. Li et al., "Strengthening and Toughening of the Co34Cr32Ni27Al3.5Ti3.5 Alloy Through Coherent L12 Nanoprecipitates," Adv Eng Mater, vol. 26, no. 10, 2024, doi: 10.1002/adem.202302111.

[19] M. Naumochkin, G. H. Park, K. Nielsch, and H. Reith, "Study of the Annealing Effects of Sputtered Bi2Te3 Thin Films with Full Thermoelectric Figure of Merit Characterization," Physica Status Solidi - Rapid Research Letters, vol. 16, no. 4, Apr. 2022, doi: 10.1002/pssr.202100533.

[20] Optessa, "Annealing Definition in Manufacturing," https://www.optessa.com/annealing-definition/, accessed on 18 June 2024

[21] Z. Wang et al., "On the kinetics of gamma prime (γ') precipitation and its strengthening mechanism in Alloy 617 during a long-term thermal aging," Materialia (Oxf), vol. 11, p. 100682, 2020, doi: https://doi.org/10.1016/j.mtla.2020.100682.

[22] Nco ~-Nickel, "Austenitic Chromium-Nickel Stainless Steels At Ambient Temperatures-Mechanical And Physical Properties A Practical Guide To The Use Of Nickel-Containing Alloys N O 2978." [Online]. Available: www.nickelinstitute.org. Accessed on 30 June 2024.

JOMAse | Received: 15-June-2024 | Accepted: 30-July-2024 | [(68) 2: 75-81]
Published by International Society of Ocean, Mechanical and Aerospace Scientists and Engineers, www.isomase.org., ISSN: 2354-7065 & e-ISSN: 2527-6085