Final Year Project Showcase Batch 2020
Year 2024

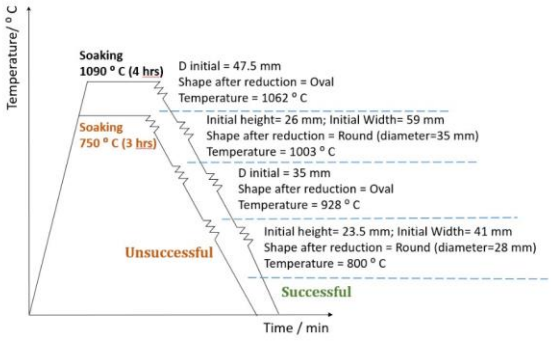
	Department: Metallurgical Engineering Programme: Metallurgical Engineering
1	**Project Title:** Production and Characterization of Stainless Steel Clad Rebar (Amreli Steel Project)
2	**Project Idea** Corrosion from harsh environments like seawater and deicing salts weakens infrastructure and increases maintenance costs. Our project aims to develop stainless steel clad rebars (SSC), an innovative construction material that combines a stainless steel (SS) outer layer with a grade 60 carbon steel core. Our primary objective is to address the issue of corrosion-induced deterioration in reinforced structures by providing inventive solutions for enhancing the durability and lifespan of rebars, reducing repair costs, and improving the sustainability of infrastructure exposed to aggressive conditions. This project seeks to merge expertise in metallurgy, mechanics, and construction to create a corrosion-resistant building material with the potential to revolutionize the field of structural engineering.
3	**Process** This project involves the production of stainless steel clad rebar, building upon the work initiated by the previous batch (batch 2019) through the liquid-solid casting method. Their production, however, was incomplete due to certain defects. We have addressed these issues by refining the production techniques, which has led to significantly improved results. Our current objective is to further enhance the process, ensuring superior quality and efficiency while preserving the corrosion resistance and mechanical integrity of the rebar. The methodology employed for the production of clad rebar using the liquid-solid casting technique involved a systematic and controlled approach. The liquid-solid casting process involves the deposition of liquid carbon steel (ASTM-A615 Grade-60) into the heated grade 316 LSS pipe, aiming for a uniform metallurgical bond at the interface. The previous batch employed both horizontal and vertical casting methods for the production of stainless steel-clad rebar. Their horizontal casting was successful, but their vertical casting, which was performed at a 90° angle, encountered issues. In our phase, we also utilized both methods. However, we adjusted the vertical casting to a 5-10° tilt, which allowed us to achieve successful results and effectively address the challenges faced by the previous group. The successfully cast sample was then rolled at 1090^0C. The clad rebar underwent post-production examination including mechanical, microstructural, and electrochemical analyses to assess the bonding contact between the carbon steel core and stainless steel layer.
4	**Outcome** After multiple attempts at stainless steel clad rebar casting and adjustments to hot rolling parameters, our batch successfully produced clad rebars with notable results: • **Microstructure:** A clear bonding interface was observed between the carbon steel core and the stainless steel surface layer, indicating a successful metallurgical bond. Ferrite and pearlite were present on the carbon steel side, while austenite was observed on the stainless steel side.

	• **Corrosion Resistance:** Electrochemical tests (PD, EIS) in artificial seawater demonstrated strong corrosion resistance of the SS-clad rebar. The SS cladding formed a protective passive layer, effectively shielding the carbon steel from chloride ion penetration and providing excellent resistance to pitting and stress corrosion cracking. • **X-Ray Diffraction (XRD):** The presence of silicon carbide particles and a prominent austenite phase on the stainless steel side was consistent with the XRD database. • **Hardness:**A progressive decrease in hardness from the stainless steel surface to the core of the clad rebar, unlike the constant hardness found in deform bars. • **Tensile Properties**: The clad rebar exhibited reduced yield strength, tensile strength, and elongation compared to deform bars. The previous batch also conducted similar trials but faced some casting and rolling defects. Their microstructural analysis confirmed the presence of ferrite and pearlite, and their clad rebars also showed reduced yield strength, tensile strength, and elongation due to these defects. Hardness measurements indicated a decrease from the surface to the core. While the previous batch demonstrated potential for corrosion resistance, they encountered challenges related to the defects.
5	**Evidence (Theoretical Basis)** The previous batch (Batch 2019) study demonstrated strong metallurgical bonding between the stainless steel and carbon steel core, featuring a yield strength of 438 MPa, tensile strength of 504 MPa, and an elongation of 7.5%. Surface hardness was measured at 24, but it did not include electrochemical testing. In contrast, our current batch (Batch 2020) of SS Clad Rebar exhibits even greater mechanical and electrochemical properties. It withstands a tensile force of 416 MPa, with a yield strength of 342 MPa and an elongation of 11%. Hardness values range from 20 to 34 HRC, averaging 29 HRC. Significantly, our current batch conducted electrochemical tests, revealing superior corrosion resistance for SS Clad Rebar, with an OCP of -0.32 V compared to -0.41 V for Grade 60. The corrosion rate was also lower at 0.106 mm/year versus 0.177 mm/year. EIS results confirmed a higher polarization resistance of 526.9 Ω cm^2, highlighting the advancements in our current batch compared to the previous one.
6	**Impact on Sustainability of Urban Regions or SDG-11 "Sustainable Cities and Communities"** This research project directly contributes to SDG-11, 'Sustainable Cities and Communities,' by addressing a critical issue faced by urban regions—corrosion-induced deterioration of infrastructure, particularly in coastal areas. The project focuses on the development and application of clad rebars, a novel construction material designed to enhance the longevity and integrity of reinforced concrete structures in urban environments. By providing a sustainable solution to combat corrosion and extend the lifespan of vital urban infrastructure, this initiative aligns with the core objectives of SDG-11. It promotes the creation of resilient, inclusive, safe, and sustainable cities and communities, fostering urban growth while addressing a pressing challenge in infrastructure sustainability.
7	**Competitive Advantage or Unique Selling Proposition** (Cost Reduction, Process improvement, Attainment of any SDG (Sustainable Development Goal), increase of market share or capturing new market or having superior performance over a competitor. In summary, any striking aspect of the project that compels the industry to invest in FYP or purchase it. Some detailed description is required in terms of how, why when what.You can select one or more from the following dropdown and delete the rest of them). Please keep relevant options, delete the rest of them, and correct the sequence

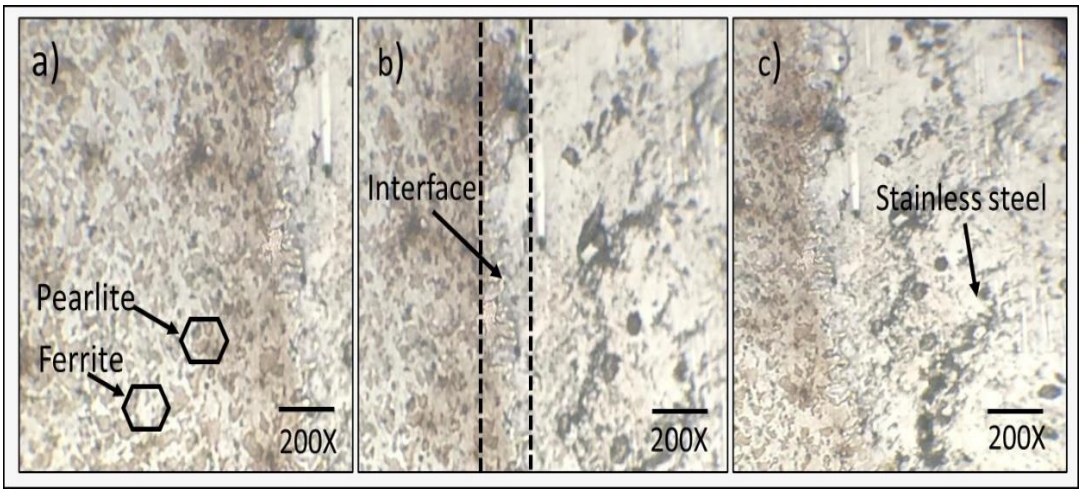
a	**Attainment of any SDG** (e.g. How it is achieved and why it is necessary for the region) By manufacturing clad rebars, this project seeks to expand employment prospects and Stimulate the steel industry's economy. The project supports SDG 9- Industry Innovation and Infrastructure by advocating for clad rebars as an innovative and advanced solution to prevent corrosion damage, this endeavor emphasizes the significance of advancing industry, innovation, and infrastructure. In line with SDG 11- Sustainable Cities and Communities, this undertaking actively contributes to the advancement of sustainable cities and communities by addressing corrosion challenges in aggressive regions. The project's goal is to increase the longevity and integrity of vital infrastructure by creating encased rebars with improved corrosion resistance, which also aligns with the broad vision of fostering sustainable urban growth.
b	**Environmental Aspect** (e.g. carbon reduction, energy-efficient, etc.) Addressing the environmental impact linked to infrastructure degradation involves the development of durable and corrosion-resistant clad reinforcement bars. This initiative promotes the responsible use of resources and the reduction of greenhouse gas emissions, contributing to the fight against climate change.
c	**Cost Reduction of Existing Product** Reducing the cost of stainless steel clad rebar can be achieved through strategic approaches such as mass production and utilizing MS (mild steel) billets with a stainless steel coating or sheet. This cost-effective method involves applying a layer of stainless steel to the surface of the less expensive MS billets. By using this approach, manufacturers can maintain the structural integrity and corrosion resistance required for rebar while significantly reducing the overall production cost.
d	**Process Improvement Which Leads to Superior Product or Cost Reduction, Efficiency Improvement of the Whole Process** (e.g. What is the issue is current process and what improvement you suggests) To enhance the quality and performance of clad rebars, it is advisable to explore a broader range of stainless-steel grades and compositions and investigate their compatibility with carbon steel cores. Additionally, the application of advanced material processing techniques such as heat treatment and alloying can further improve the mechanical properties of clad rebars, adapting them to specific performance requirements. These advancements can lead to the creation of more durable and resilient reinforced concrete structures, addressing corrosion challenges and promoting sustainable infrastructure development in the construction industry.
e	**Expanding of Market share** (e.g. how it expand and what is the problem with the current market Expanding market share is a critical objective for businesses seeking growth and sustainability. To embark on this journey, thorough market analysis is paramount, allowing companies to identify and address existing market problems. These issues might include market saturation, fierce competition, shifting consumer preferences, or limited growth potential. To overcome these challenges, companies can employ a variety of strategies. Product or service differentiation, targeting new customer segments, market penetration, geographic expansion, mergers and acquisitions, and effective marketing and branding campaigns are all viable approaches. Additionally, prioritizing the customer experience, adopting advanced technologies, and aligning with sustainability and social responsibility values can contribute to the successful expansion of market share. However, it's important to acknowledge that expanding market share is not without its challenges, including increased

	competition and resource investments, making strategic planning and adaptation crucial in achieving this goal.	
f	**Capture New Market** (e.g. Niche market or unaddressed segment) A new market opportunity for stainless steel has emerged in Pakistan, as there is currently no local production of this material.	
9	**Target Market** (Industries, Groups, Individuals, Families, Students, etc) Please provide some detail about the end-user of the product, process, or service Our research on clad rebars has the potential to unlock new opportunities in the Pakistani market, including construction firms, infrastructure developers, steel manufacturers, engineers, architects, R&D institutions, and environmental organizations. It can foster innovation and resilience in critical infrastructure, and potentially even attract international attention and partnerships in the field of corrosion-resistant materials.	
9	**Team Members** (Names along with email address	1. Aena Malik malik4300606@cloud.neduet.edu.pk 2. Alishba Masood Siddiqui siddiqui4302692@cloud.neduet.edu.pk 3. Muhammad SabeehBaig baig4301341@cloud.neduet.edu.pk 4. Muhammad Ather Hussain Siddiqui siddiqui4208428@cloud.neduet.edu.pk 5. Ahsan Muneer muneer420563@cloud.neduet.edu.pk 6. SyedaBazlahAshfaq Rizvi rizvi4202083@cloud.neduet.edu.pk
10	**Supervisor Name**(along with email address)	1. Dr. M. Ali Siddiqui m.siddiqui@cloud.neduet.edu.pk 2. Engr. Noman Sajjad (Amreli Stee lLtd., Industrial 3. Prof. Dr. Ali Dad Chandio (Co-Supervisor)
11	**Videos (If any)**	https://drive.google.com/drive/folders/1IyzepgVAu40LiG5-HcrqYprwDxuyIj5c?usp=sharing ROLLING OF VERTICALLY CASTED SAMPLE. VERTICALLY CASTED SAMPLE AT AMRELI STEELS.

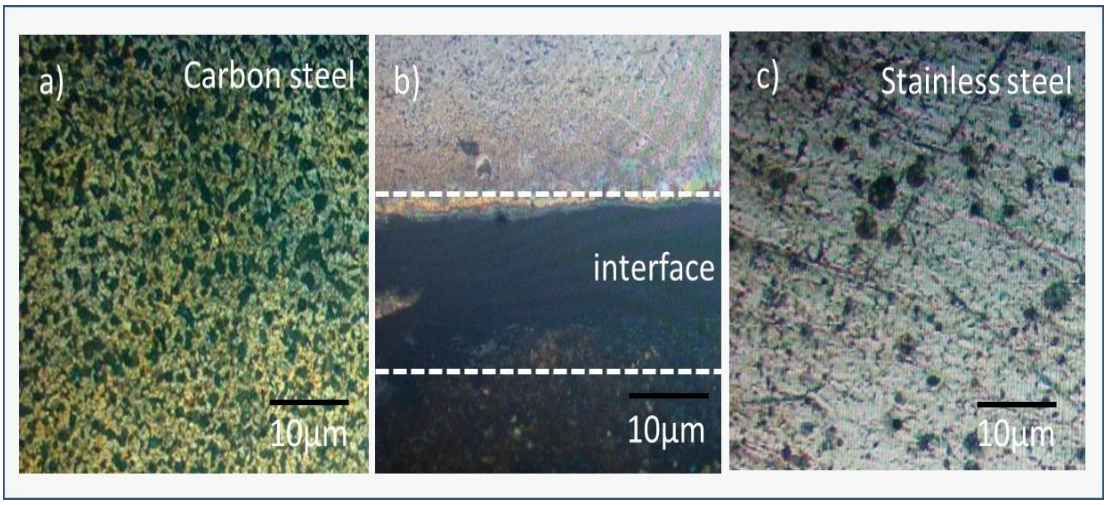
Vertical casting *Vertical casted*



rolli *Sample rolled*

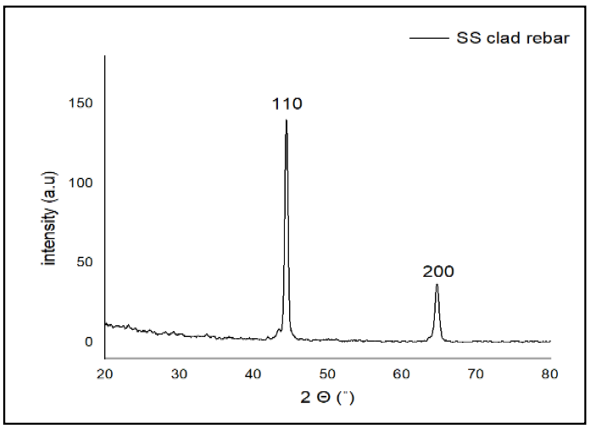


Microstructure of SSC rebar

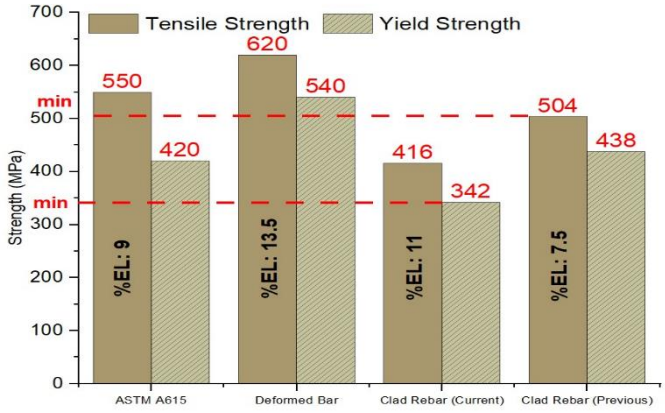


Microstructural analysisusing imageanalyzer

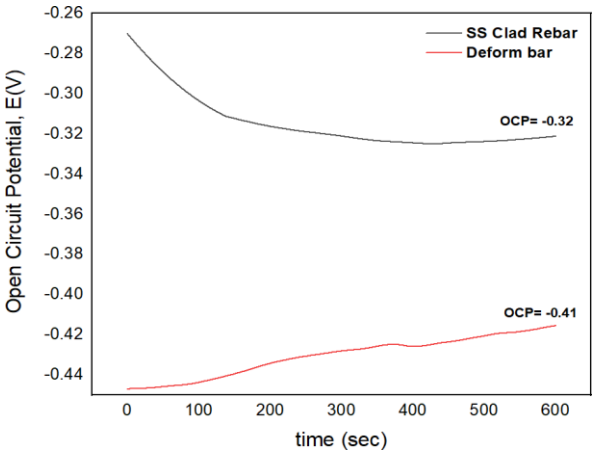
Stereo micrograph ofinterfaceof SSCrebar



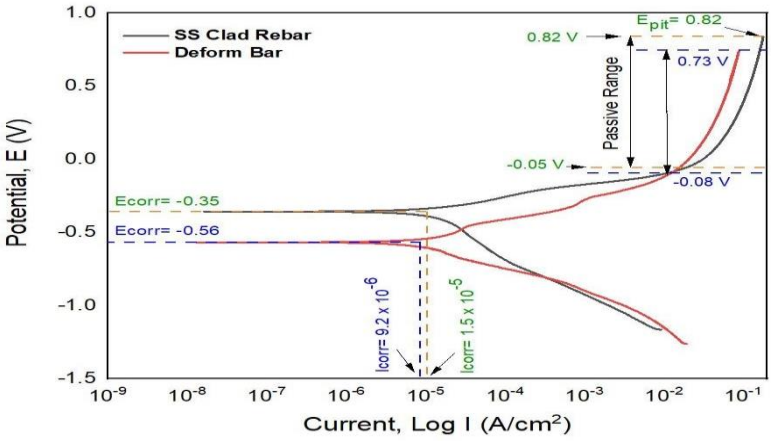
XRD plot of SS-clad rebar



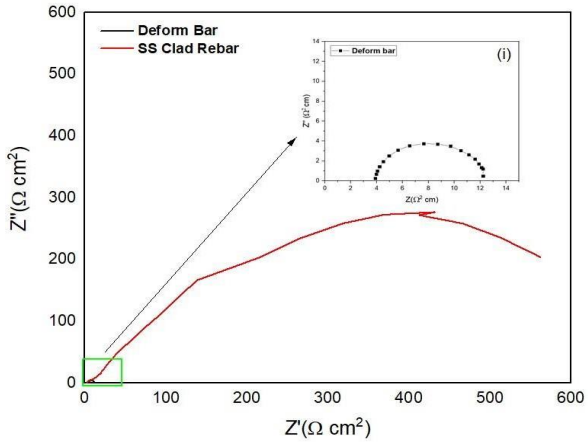
Bar graph of tensile results



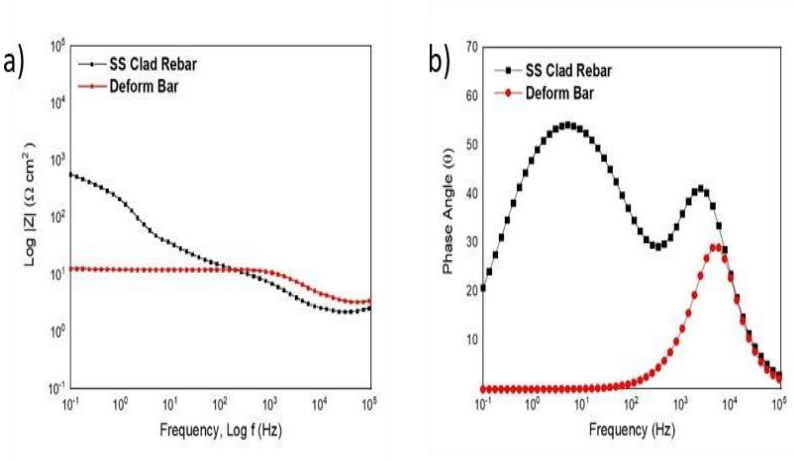
Comparisontablefor OCPValues



PDcurves ofSSCrebarand derformbar



Comparisonof Nyquist Plotof SSClad Rebar andDeform bar



(a)BodeMagnitude;(b)BodeAngle