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Experimental Approach for Enhancing Performance in Submerged Arc Welding Process

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Abstract: Submerged Arc Welding (SAW) is a popular method across many industries because it consistently produces strong, high-quality welds. But getting the best possible performance from this process isn't always straightforward. That's because many different factors—like welding settings and environmental conditions—interact in complex ways. In this study, we take a predictive approach to improve SAW performance. Our goal is to make the welds not only stronger but also more resistant to corrosion and structurally sound at a microscopic level. To test this, we ran salt spray corrosion tests to simulate harsh conditions and see how well the welded joints hold up. We also used a high-tech microscope system, the Metscope Pro, to closely study the microstructure of the welds. We experimented with different welding settings—like current, voltage, travel speed, and the type of flux used—following a planned experimental design. What we found was pretty clear: by fine-tuning these parameters, we significantly boosted the corrosion resistance and created more uniform and refined microstructures. That means stronger, longer-lasting welds. This work provides practical insights for anyone looking to adapt the SAW process for tough environments where performance really matters.

Keywords: *Submerged Arc Welding, Corrosion Testing, Microstructure Analysis, Predictive Modeling, Weld Quality, Metscope Pro, Parameter Tuning.*

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I. INTRODUCTION

Submerged Arc Welding (SAW) is a popular welding technique used in industries like shipbuilding, pipeline construction, and heavy machinery manufacturing. It's known for its high deposition rates, deep weld penetration, and consistent weld quality. However, there are still challenges to address, such as too much heat input, the possibility of weld defects, and limited flexibility in the process. These issues mean there's always room for improvement to make the process more efficient and reliable.

In SAW, a consumable electrode (either tubular or solid) is continuously fed into the welding arc, which can be fully automatic or semi-automatic. The arc stays flat and is maintained between the electrode and the workpiece. As the electrode melts, a layer of granular flux forms over the weld pool, protecting it and providing a stable environment for the welding to take place. Some of the flux melts and forms a blanket that helps keep the process stable.

Flux plays a big role in shaping the weld, affecting things like bead geometry, strength, and load capacity. It also impacts the chemical composition, mechanical properties, and microstructure of the weld metal. The flux used in SAW can include materials like lime, silica, manganese oxide, and calcium fluoride. When the flux melts, it becomes conductive, allowing the welding current to flow steadily between the electrode and the workpiece.

Fluxes are a key part of SAW, serving many functions: protecting the weld pool from contamination, keeping the arc stable, and influencing the final properties of the weld. These fluxes are usually granulated and can be made through different processes like fusion, bonding, or agglomeration. Some of the most commonly used fluxes in SAW include Ador Flux and GE Flux, both of which are well-known and widely used for specific types of welding jobs.

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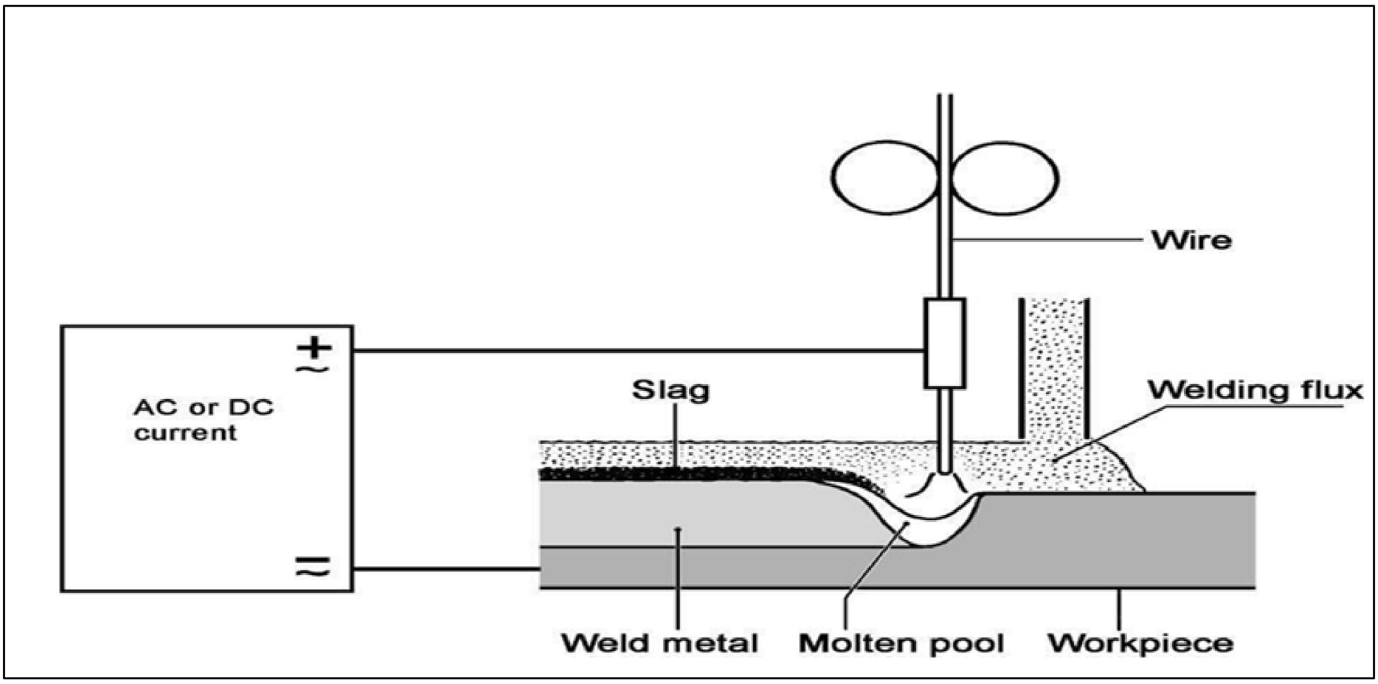

Fig 1 Principle of Submerged Arc Welding

Fluxes play a vital role in the Submerged Arc Welding (SAW) process. They're not just there to cover the weld — they actually do a lot more. For starters, they protect the molten weld pool from getting contaminated by the atmosphere, help stabilize the arc, and significantly influence the strength, structure, and chemistry of the final weld. These fluxes come in the form of granules and can be made through different methods such as fusing, bonding, or agglomerating, depending on the intended use and performance requirements.

Two widely used types of flux in SAW are Ador Flux and GE Flux. Ador Flux, developed by Ador Welding Ltd., is well-regarded in the welding world for its versatility and performance. It's designed for a wide range of industrial applications including structural steelwork, pressure vessels, pipelines, shipbuilding, and heavy equipment fabrication. These fluxes are engineered to deliver reliable results and adapt to various welding conditions.

GE Flux, on the other hand, is another trusted name in the SAW space. It's built to handle tough welding tasks, especially where precision and durability are critical. Commonly used in industries like pipeline construction, shipbuilding, and structural fabrication, GE Flux is valued for its consistent performance, deep penetration, and ability to produce high-quality welds with excellent mechanical properties.

II. METHODOLOGY

➢ *Experminental Details*

MS 2062 is a commonly used grade of mild steel, especially popular in structural and general welding applications. Thanks to its low carbon content, it's easy to work with, especially when it comes to welding, and offers decent strength for everyday construction needs. You'll often find it being used in buildings, machinery, and general fabrication—basically, anywhere that doesn't require super high-strength materials.

One of the things that makes MS 2062 so versatile is its balance of toughness and ductility, which means it can handle bending and shaping without cracking. It's also fairly resistant to rust under normal atmospheric conditions, although in more aggressive environments, it usually needs a protective coating to prevent corrosion. If needed, the mechanical properties of MS 2062 can be improved through processes like heat treatment or cold working, depending on what the specific job calls for.

➢ *Salt Spray Corrosion Test*

The Salt Spray Corrosion Test, also known as the Salt Fog Test, is a well-known method used to check how well materials or coatings can hold up against corrosion. It creates a controlled, corrosive environment—kind of like a sped-up version of what you'd find in nature—to see how materials react over time. This test is especially useful for evaluating the durability of protective coatings, helping manufacturers figure out how long their products might last in harsh conditions. The go-to standard for this test is ASTM B117, which is widely accepted across industries for its consistency and reliability.

➢ *Microstructure Analysis*

The Metscope Pro IM30M is a top-tier metallurgical microscope that's widely used for examining the microstructure of different materials like metals, alloys, ceramics, and polymers. It's a go-to tool in fields such as metallurgy, material science, and engineering when there's a need to take a closer look—literally—at how materials are built from the inside out. This microscope comes packed with advanced features that make it perfect for high-resolution imaging, detailed image analysis, and evaluating surface

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textures. With magnification levels ranging from a modest 40x all the way up to an impressive 2000x, it allows researchers and engineers to get an in-depth view of the fine details that affect material performance.

III. IMPLEMENTATION

For this work, IS 2062 E-350 grade steel is used as the base material, with plates measuring 300 mm by 140 mm and 16 mm in thickness. The welding process is carried out using Submerged Arc Welding (SAW), where three different combinations of electrode wire and flux materials are tested. The welding parameters are set with an arc voltage of 30V and a welding speed of 22 meters per minute. These parameters are determined using a trial-and-error approach, keeping the mechanical performance of the welds in mind. To assess corrosion resistance, a Salt Spray Corrosion Test is performed following the ASTM B117 standard. For microstructure and metallurgical examination, the welded samples are observed under a Metscope Pro microscope, model IM30M, which helps identify changes in the weld zone structure.

The welding is done using an automated SAW machine with a consumable electrode, and the arc is completely covered with granulated flux powder. Sheets of IS 2062 steel are cut down to 150 mm x 100 mm x 16 mm using a power saw and thoroughly cleaned before welding. A closed butt joint configuration is used for autogenous welding, meaning no filler material is added. To reduce the risk of distortion during the process, copper sinks are clamped in place, and extra care is taken to ensure the sheets are properly aligned. These assembly precautions play an important role in maintaining weld quality. It's worth noting that in SAW, several process variables—like welding speed, wire feed rate, current, and voltage—can significantly influence the quality of the weld. From earlier studies, it's clear that welding speed, in particular, has a major effect on the final weld characteristics.

- Tack Welding
- Back-to-Back Assembly

➢ *Salt Spray Corrosion Test*

ASTM B117 – "Standard Practice for Operating Salt Spray (Fog) Apparatus" This standard specifies the procedure for performing the salt spray (fog) test, which is designed to simulate the effect of a corrosive, salt-laden environment (such as coastal or marine areas) on materials or coatings. The test uses a salt mist or fog to accelerate corrosion processes, providing an accelerated method to evaluate the material's resistance to corrosion.

Fig 2 ASTM B 117 Sait Spray Chamber

The salt spray test is carried out inside a sealed chamber where the sample is continuously exposed to a fine mist of saltwater—usually a 5% sodium chloride (NaCl) solution. This setup is designed to simulate a harsh, corrosive environment and see how well a material or coating can stand up to it. The conditions inside the chamber, such as temperature, humidity, and airflow, are kept constant to ensure that the results are reliable and can be repeated. The salt solution is always freshly mixed and filtered to avoid any contamination that could skew the results.

The chamber is typically maintained at a steady 35°C (or 95°F), and the pH of the salt solution is kept within a slightly neutral range of 6.5 to 7.2. The mist is sprayed at a controlled rate— about 1 to 2 milliliters per hour for every 80 square centimeters of the sample's surface area. The length of the test can vary depending on what's being tested, ranging anywhere from 48 hours to several weeks. For quicker insights, accelerated test durations like 48, 72, 100, or even 1000 hours are often used to mimic longer-term exposure in a shorter time frame.

While this test is great for evaluating how well coatings like paint, plating, or galvanization hold up against corrosion, it's worth noting that it doesn't always reflect how the base material will behave in real-world conditions—especially in environments with different stress factors like UV exposure or alternating wet and dry cycles.

Cut the MS 2062 specimens to the required size and shape, typically 300mm x 130mm x 16mm or similar dimensions depending on the standard. Clean the specimens to remove any surface contaminants. the specimen can be coated with protective coatings (paint, galvanizing, etc.). The specimens are placed in the salt spray chamber, ensuring that they are securely fixed in place. The specimens are oriented at an angle (typically 15° to 30°) to prevent excess accumulation of salt on the surface and to allow even exposure. The chamber is activated to begin spraying the salt solution onto the specimens. The salt mist is uniform, with a spray rate of 1–2 mL per 80 cm² of specimen surface per hour. The salt spray is continuously mist the specimens for the duration of the test. Constant temperature of 35°C (95°F) in the chamber is maintained.

The pH of the salt spray solution is between 6.5 and 7.2. This can be checked regularly and adjusted if necessary by adding either a small amount of sodium hydroxide ($NaOH$) or hydrochloric acid (HCl). The test duration depends on the specific standard or requirement. Typically, tests last for 24 hours to several weeks, with observations taken at specific intervals (e.g., every 24 hours). After the specified exposure time, the specimens are removed from the chamber. Specimens are cleaned to remove any excess salt residue using distilled water. Inspection is done on the specimens for the extent of corrosion. A standardized rating system (e.g., ASTM B117, ISO 9227) is used to assess the degree of corrosion. The specimen is weighed before and after the test to determine the corrosion rate. A higher mass loss indicates higher corrosion. The Salt Spray Corrosion Test is a critical method for evaluating how well materials like MS 2062 (or similar steels) can withstand saltwater exposure.

➢ *Microstructure Analysis*

Microstructure analysis is the process of examining the internal structure of materials at a microscopic level. This is usually done using different types of microscopy, such as optical, electron, or X-ray microscopy. It's an important method for understanding how materials behave, perform, and hold up under various conditions. It's especially useful in fields like materials science, metallurgy, and quality control in manufacturing. By looking at the microstructure, we can get insights into a material's properties and performance, which is key for improving manufacturing processes, enhancing material qualities, and ensuring high product quality.

When analyzing the microstructure of MS 2062 (a common mild steel used in structural applications), the first step is to prepare a small piece of the material—about 10 to 20 mm in size. This piece is cut using an abrasive cutter to avoid altering the material with excessive heat. The sample is then mounted in a resin, like bakelite or epoxy, to make handling easier, especially for small or oddly shaped samples. After the resin is fully cured, the sample is polished, and high-resolution images are taken to study the material's grain structure, phase distribution, and any inclusions. This detailed analysis helps to better understand the steel's properties and how it will perform in real-world applications.

Fig 3 Metscope Pro IM30M

➢ *Specimen Preparation For Microstructure Analysis*

Specimen preparation is necessary for to study its microstructure, because the metallurgical microscope makes use of the principle of reflection of light to obtain the final image of the metal structure. Satisfactory metallographic results can be obtained only, when the specimen has been carefully prepared. Even the most costly microscope cannot reveal the metal structure if the specimen has been poorly prepared.

- *Steps Involved.*

Procedure for preparing the specimen for micro examination is as follows

✓ *Selection of Specimen*

When investigating the properties of a metal or alloy, it is essential that specimen should be selected from that area of the alloy plate or casting which can be taken as representative of the whole mass.

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✓ *Cutting of the Specimen*

After selecting particular area in the whole mass, the specimen may be removed with the help of a saw.

▪ *Obtaining Flat Specimen Surface*

It is necessary to obtain a reasonably flat specimen surface on the specimen. This is achieved by using fairly coarse file or machining or grinding, by using a motor driven belt.

Fig 4 Specimen for Microstructure Analysis

IV. RESULTS AND DISCUSSIONS

The specimens are palced in salt spray chamber for corrosion test for over 96 hrs. The salt mist is uniform, with a spray rate of 1–2 mL per 80 cm² of specimen surface per hour. The salt spray is continuously mist the specimens for the duration of the test.

- *Nature Of Test : Salt Spray Test Test*
- *Method : Astm B 1 L7*
- *Equipment Used : Salt Spray Chamber*

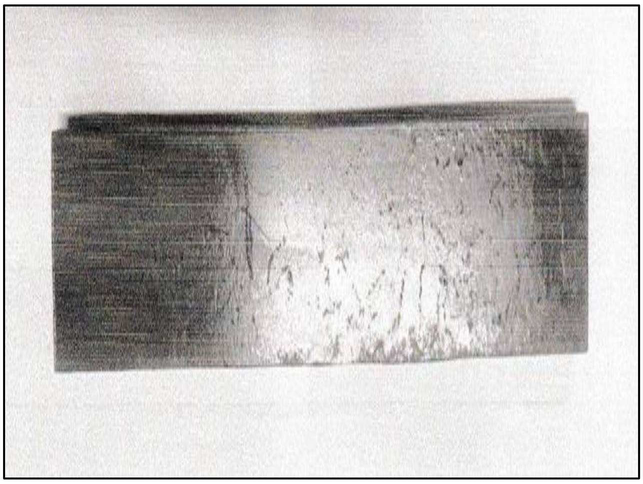

Fig 5 Specimen after Corrosion Test for 96 Hrs

Table 1 Salt Spray Corrosion Test

S NO	PARAMETERS	OBSERVATIONS
1	No of specimens tested	Two
2	Concentration of solution	5% NACL
3	Test temperature	35 degrees of celsius
4	Volume of test solution collected	2.0ml/Hr/80 cm
5	pH of test solution	6.99 to 7.02
6	Cleaning after test	Rinsed with running water and dried.
7	Test period	96 Hrs
8	Interruption if any	None, except for daily observation
9	Observations	No Rust Observed at the end of 96 hrs

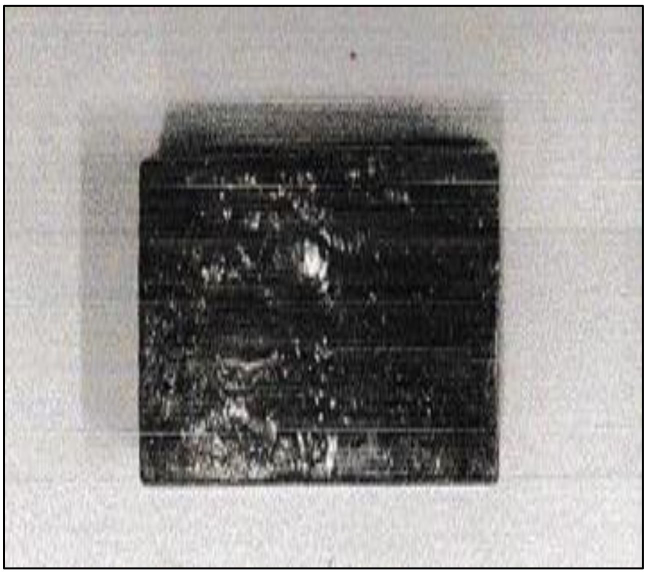

Fig 6 Base Metal Specimen after Corrosion Test

Before the corrosion test the sample pieces are coated with epoxy resin or spray paint to remove any contaminants on the surface of metal. The salt spray corrosion test is performed on the base metal and also on the weld metal zone to understand the difference of corrosion effect on the area without the effect of submerged arc welding and also on the specimen with weld zone. The results indicated the no rust is observed on the both the samples for 96 hrs indicating the material of high corrosion resistance.

Result indicates that the material has exhibited excellent resistance to corrosion under the test conditions. The MS 2062 material was coated (e.g., galvanized, painted, or otherwise treated), the protective layer effectively prevented the salt solution from reaching the metal surface. MS 2062 is a low-carbon mild steel, and its corrosion resistance can be enhanced if it contains trace amounts of elements like silicon, manganese, or phosphorus.

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➢ *Microstructure*

Properties of steel depend on the microstructure. Decrease in the size of grains and decrease in the amount of pearlite improves the strength, ductility and toughness of the steel.

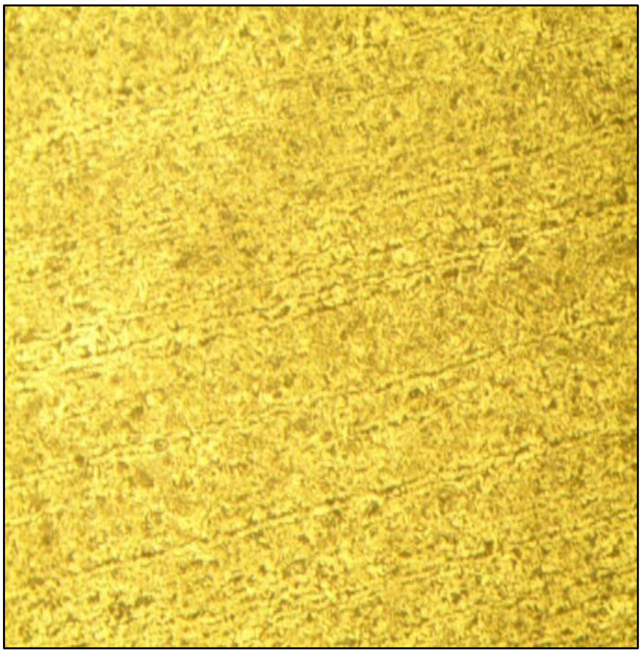

Fig 7 Microstructure of Welded Specimen(1) at 100X

Microstructure shows that ferrite and pearlite structures are formed in the heat affected zone. The light coloured region of mild steel is the ferrite. Grain boundaries between ferrite grains can be seen quite clearly. Dark regions are called Pearlite.

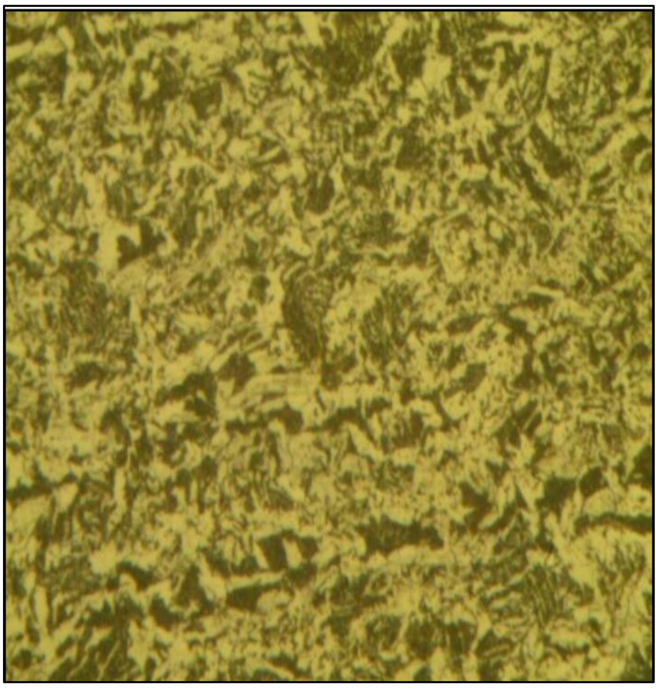

Fig 8 Microstructure of Welded Specimen(1) at 500x

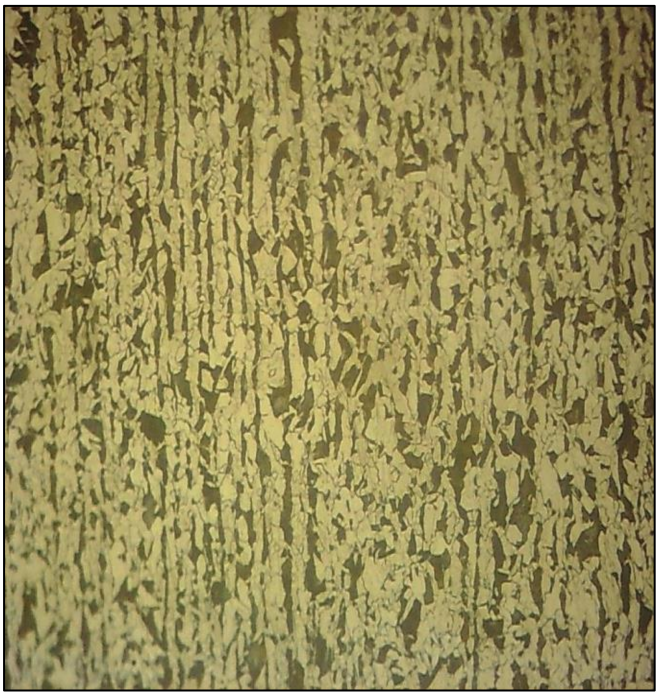

Fig 9 Microstructure of Welded Specimen(2) at 150x

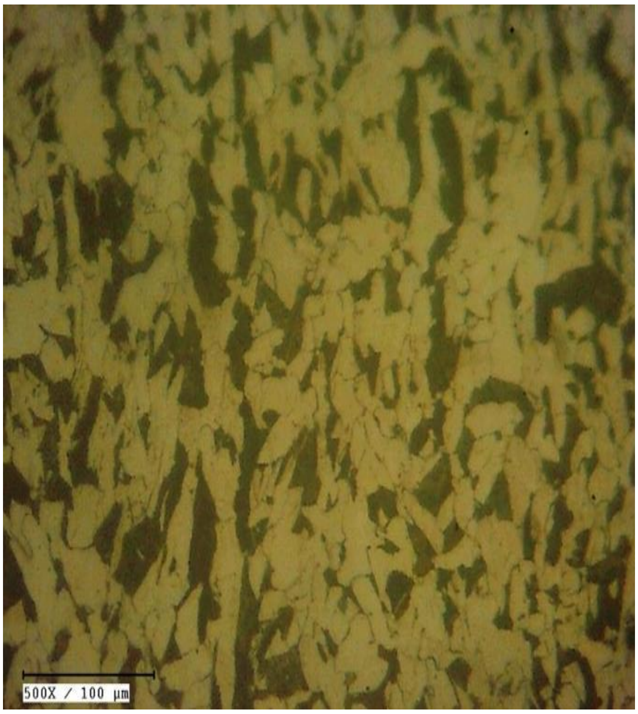

Fig 10 Microstructure of Welded Specimen (2) at 500x

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Fig 11 Microstructure of Welded Specimen(3) at 200x

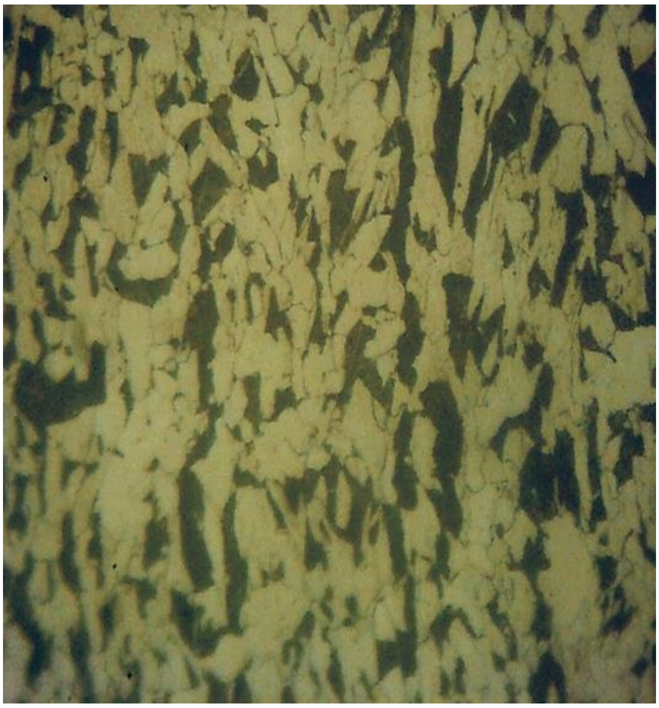
Fig 12 Microstructure of Welded Specimen (3) at 500x

As MS2062 steel cools from the austenite phase, ferrite forms, especially since it's a low- carbon steel with less than 0.25% carbon. Ferrite helps improve the steel's weldability, machinability, and toughness. However, it comes with a trade-off—it lowers strength and hardness when compared to harder phases like pearlite. The amount of ferrite in the material is influenced by how quickly the steel cools and the heat treatment it undergoes. If the cooling rate is slow, more ferrite is produced, which increases ductility. On the other hand, faster cooling or adding certain alloys can refine the ferrite structure and boost strength. Under a microscope, ferrite appears as light-colored areas, with darker pearlite scattered throughout. Methods like normalizing can refine the ferrite grain structure, optimizing the steel's mechanical properties for use in structural applications.

Pearlite forms when austenite transforms at lower temperatures and consists of alternating layers of ferrite and cementite. In MS2062, due to its low carbon content, pearlite is present in smaller amounts compared to ferrite. Still, pearlite is important because it increases the steel's strength and wear resistance. The amount and texture of pearlite depend on how quickly the steel cools. Slower cooling results in coarser pearlite, while faster cooling creates finer pearlite, which increases hardness. When viewed under a microscope, pearlite shows up as darker regions mixed with the lighter ferrite. Heat treatments like normalizing can further refine the pearlite structure, helping to strike a balance between strength and toughness in MS2062.

V. CONCLUSION

The experimental approach using the Metscope Pro, Model No: IM30M, for microstructure analysis in the context of enhancing the performance of the Submerged Arc Welding (SAW) process can provided significant insights. Microstructure analysis has demonstrated its effectiveness in enhancing the performance of the SAW process. Optimized welding parameters result in a fine grained, defect-free microstructure, improving mechanical and corrosion properties. The advanced imaging and analysis capabilities of Metscope Pro have been instrumental in deriving these conclusions, providing a robust framework for further process improvements. Weld metal exhibits refined grains in the heat-affected zone (HAZ) and weld zone due to the thermal cycles of SAW.

The Salt Spray Corrosion Test (ASTM B117) has demonstrated the critical influence of welding parameters and microstructural features on the corrosion resistance of SAW joints. Welds produced with optimized parameters exhibited minimal corrosion, even under aggressive saline conditions. Incorporating process enhancements such as flux optimization, post-weld treatments, and protective coatings can further improve the durability of SAW joints, making them suitable for applications in corrosive environments.

Welded joints exhibited consistent resistance to salt spray corrosion, indicating a good weld quality and minimal defects in the weld metal and heat-affected zone (HAZ). Optimized welding parameters such as voltage, current, and travel speed enhanced the corrosion resistance of the weld. Excessive heat input led to the formation of coarse grains and localized corrosion in the HAZ.

Protective coatings (e.g., galvanization or paint) were applied, their integrity and adhesion significantly contributed to the corrosion resistance of the welds. Over longer periods, the test results may reveal gradual degradation, with corrosion potentially initiating at the weld. The use of fluxes with corrosion-inhibiting properties improves the performance of SAW joints under salt spray conditions. The salt spray corrosion test on MS 2062, conducted according to standards like ASTM B117, provides critical insights into the corrosion resistance of the material in saline environments.

No rust is observed during the test duration (e.g., 96 hours), it indicates excellent corrosion resistance under the test conditions. This result suggests the material or protective measures (e.g., coatings, treatments) effectively prevented corrosion. Protective coatings (e.g., galvanization, epoxy paint, or passivation) greatly enhanced the material's resistance to corrosion. Since MS 2062 has been welded, the heat-affected zone may have slightly different corrosion resistance due to microstructural changes. But no rust is observed for both the base metal and the heat affected zone.

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