INTERGRANULAR CORROSION TEST OF SS316L MADE BY POWDER BED FUSION

A PROJECT REPORT

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BONAFIDE CERTIFICATE

Certified that this project report **"INTERGRANULAR CORROSION TEST OF SS316L MADE BY POWDER BED FUSION"** is the bonafide work of

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INTERNAL EXAMINER	**EXTERNAL EXAMINER**

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TABLE OF CONTENTS

ABSTRACT:

The aim of this project is to investigate the intergranular corrosion resistance of SS316L parts produced by powder bed fusion technique (PBF) using the ASTM A262 Practice A test method. Intergranular corrosion is a type of localized corrosion that occurs along grain boundaries, which can severely affect the mechanical properties and durability of the material.In this study, SS316L specimens produced by PBF will be subjected to the ASTM A262 Practice A test to evaluate their resistance to intergranular corrosion. The test will involve immersing the specimens in a corrosive solution and examining them for signs of corrosion, such as cracking or loss of material.

The test results will be analyzed and compared to the ASTM A262 acceptance criteria to determine whether the SS316L parts produced by PBF meet the required intergranular corrosion resistance standards. The microstructure of the specimens will also be examined using scanning electron microscopy (SEM) to investigate any potential correlation between microstructure and corrosion resistance.

This project will contribute to the understanding of the intergranular corrosion behavior of SS316L parts produced by PBF and provide valuable insights into the suitability of PBF for producing parts that require high intergranular corrosion resistance. The findings of this project could potentially lead to improvements in the production process of SS316L parts and broaden their applications in various industries.

CHAPTER 1

1.Introduction:

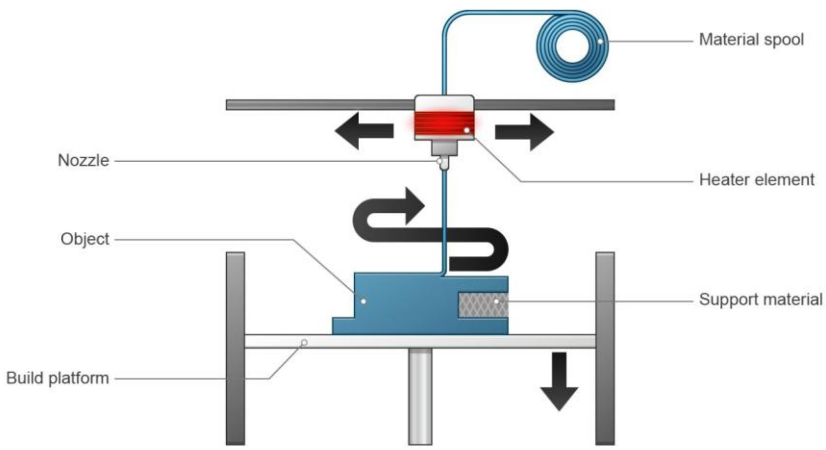
1.1 ADDITIVE MANUFACTURING

Additive manufacturing, also known as 3D printing, is a revolutionary technology that has transformed the manufacturing industry. It is a process of creating three-dimensional objects by adding successive layers of material on top of each other, as opposed to traditional subtractive manufacturing, where material is removed from a larger block to create the desired shape. Additive manufacturing has the potential to greatly reduce the time, cost, and waste associated with traditional manufacturing, while also allowing for greater design freedom and customization. Additive manufacturing offers a number of benefits over traditional manufacturing methods. One of the biggest benefits is the ability to create highly complex geometries that would be impossible or difficult to produce using traditional methods. This allows for greater design freedom and customization, which can be particularly beneficial in industries such as aerospace, where weight reduction and optimization are key.Additive manufacturing can also greatly reduce the time and cost associated with traditional manufacturing. With traditional methods, creating a new part or product can be a time-consuming and expensive process, requiring multiple iterations and prototypes. With additive manufacturing, parts can be produced quickly and efficiently, with little waste and no need for expensive tooling.

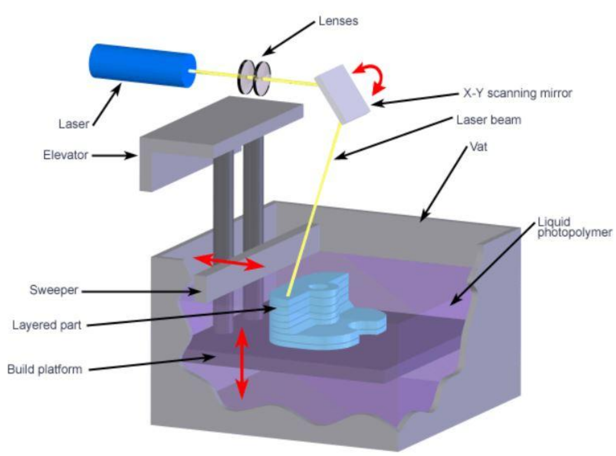
1.2 TYPES OF ADDITIVE MANUFACTURING PROCESS

There are several types of additive manufacturing technologies, each with its unique advantages and limitations. Here are some of the most common types:

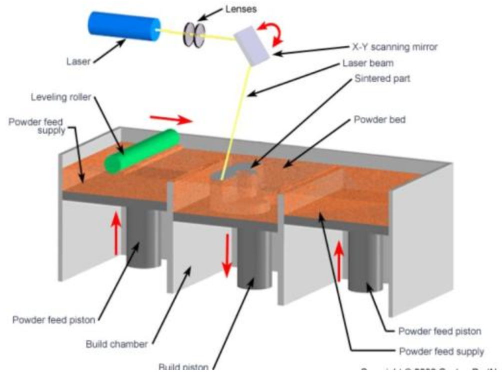
1. Fused Deposition Modeling (FDM) - This technique involves extruding a thermoplastic material through a heated nozzle that moves in the X and Y directions, layer by layer, to create the final object. FDM is popular for its low cost and ease of use.



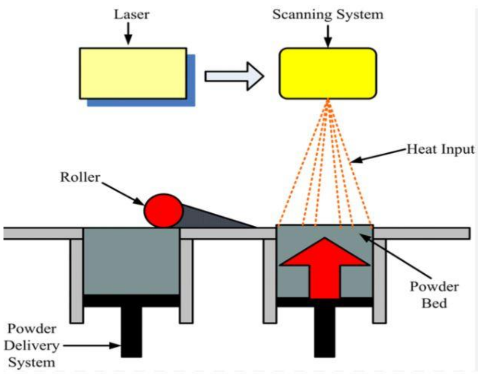
2. Stereolithography (SLA) - This process uses a laser to solidify a liquid resin, layer by layer, to create the final object. SLA is known for its high level of detail and accuracy.



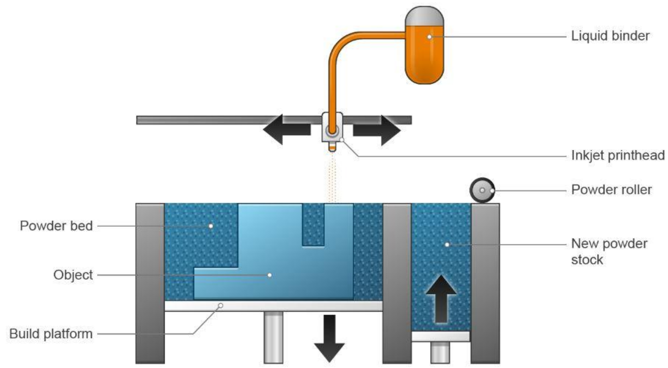
3. Selective Laser Sintering (SLS) - This technique uses a laser to selectively fuse powdered material, typically a polymer or metal, layer by layer to create the final object. SLS is popular for creating complex geometries.



4. Direct Metal Laser Sintering (DMLS) - Similar to SLS, but it uses metal powder and a laser to create fully dense metal parts.



5. Binder Jetting - This process involves jetting a binder material onto a powder bed, layer by layer, to selectively bind the powder and create the final object. Binder jetting is commonly used for producing ceramic and metal parts



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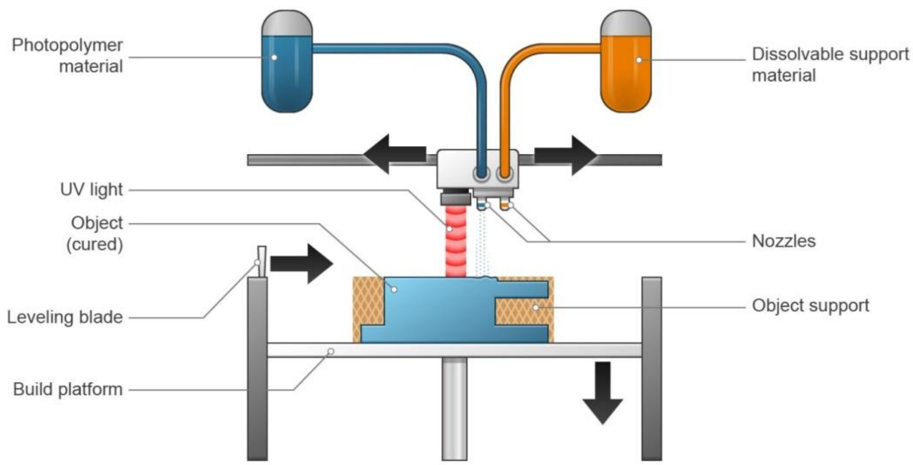
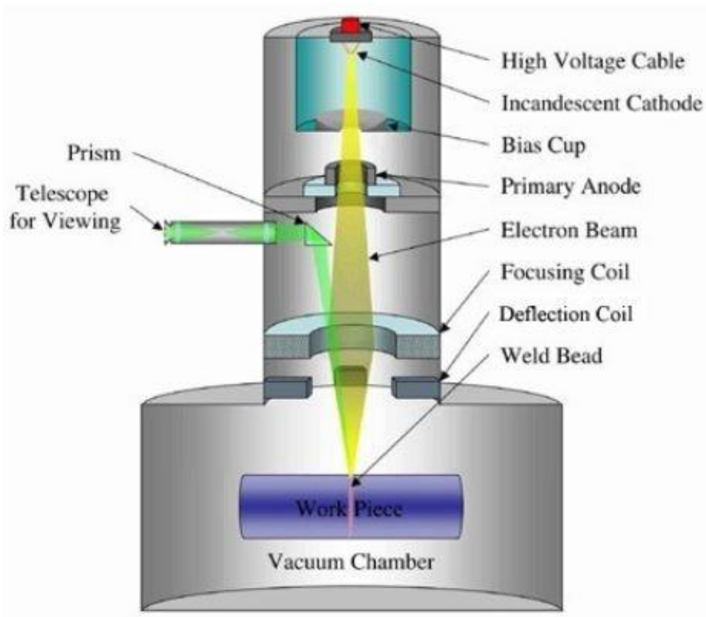
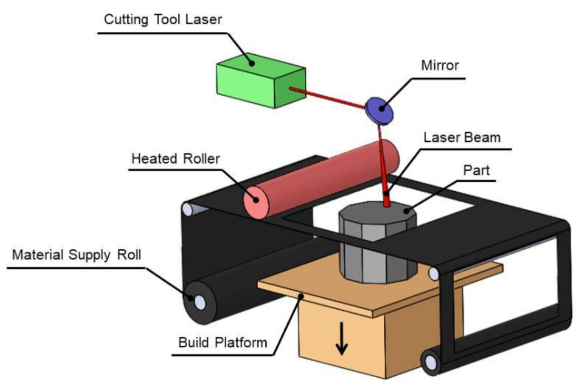
6. Material Jetting(MJ) - This technique involves jetting a liquid material, layer by layer, onto a build platform to create the final object. Material jetting is commonly used for producing high-resolution, multi-material parts.



7. Electron Beam Melting (EBM) - This process involves using an electron beam to melt and fuse metal powder together to create the final object. EBM is commonly used for producing complex metal parts with high accuracy.



8. Sheet lamination (LOM) is an additive manufacturing technique that involves layering and bonding sheets of material to create a 3D object. It is also known as laminated object manufacturing and uses materials such as paper, plastic, and metal sheets. The process involves cutting the sheet material into the required shape using a laser or knife, and then bonding the layers together using an adhesive or heat. Sheet lamination is a relatively low-cost and fast method for creating 3D objects, but it may not be suitable for producing parts with high precision or complex geometries. The quality of the final product depends on the thickness and uniformity of the sheet materials used, as well as the accuracy of the cutting and bonding processes



9. Directed Energy Deposition (DED) is an additive manufacturing (AM) technology that uses focused thermal energy, such as a laser or an electron beam, to melt and fuse metallic powders or wires layer-by-layer to build complex 3D geometries.

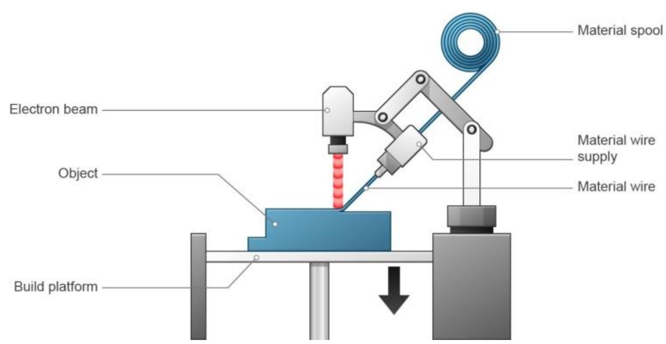
DED processes can be classified into three main categories:

- Laser Engineered Net Shaping (LENS)
- Electron Beam Additive Manufacturing (EBAM)
- Wire Arc Additive Manufacturing(WAAM)

LENS is a type of DED process that uses a high-powered laser beam to melt metallic powders or wires onto a substrate to build 3D parts. The laser beam is typically scanned across the powder bed in a controlled pattern, melting the powder and fusing it to the underlying material. The process is repeated layer-by-layer to build up the part.

EBAM is another type of DED process that uses an electron beam instead of a laser to melt metallic powders or wires. The electron beam is focused on the powder bed, which melts and fuses the powder onto the substrate to create the 3D part.

WAAM is an additive manufacturing process that uses an electric arc to melt a metallic wire, which is then deposited layer-by-layer onto a substrate to create a 3D part. WAAM offers high deposition rates, the ability to work with a wide range of metals, and is a low-cost, high-speed process that can produce large parts



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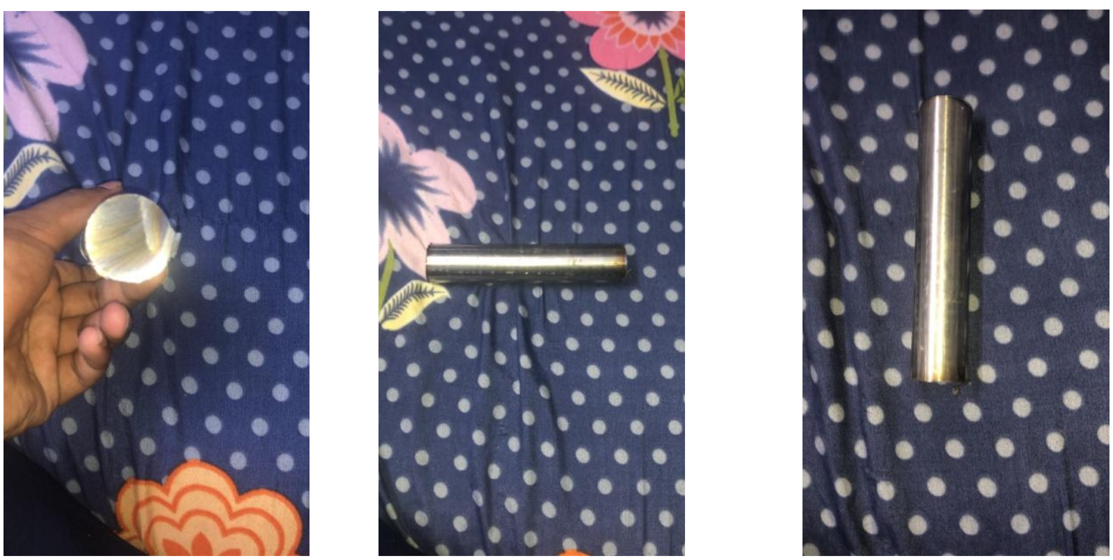
1.3 STAINLESS STEEL (316 AND 316L)

Stainless steel alloys are widely used in various industries due to their excellent mechanical properties and corrosion resistance. However, these alloys can be susceptible to intergranular corrosion, which can lead to severe damage and failure. The intergranular corrosion test is an essential method for evaluating the susceptibility of stainless steel alloys to this type of corrosion.SS316 and SS316L are two commonly used stainless steel alloys that differ in their carbon content. SS316 contains a higher carbon content than SS316L, which makes it more susceptible to intergranular corrosion. The intergranular corrosion test of SS316 and SS316L is crucial to evaluate their corrosion resistance and determine their suitability for various applications.



Commercial sample (SS316L)

SS316 is a type of stainless steel that is widely used in various applications due to its excellent corrosion resistance, high ductility, and good mechanical properties. The "SS" in SS316 stands for stainless steel, and the "316" refers to the grade of stainless steel, which contains 16-18% chromium, 10-14% nickel, and 2-3% molybdenum. This composition provides SS316 with excellent corrosion resistance, particularly against pitting and crevice corrosion in chloride environments, making it suitable for use in harsh environments. SS316 is commonly used in applications such as chemical and pharmaceutical processing equipment, food processing equipment, medical implants, and marine equipment, among others. SS316 is also commonly used in combination with other materials such as polymers and ceramics to create composites with enhanced properties.

SS316L refers to a specific type of stainless steel that is commonly used in various applications due to its excellent corrosion resistance, high ductility, and good mechanical properties. The "SS" in SS316L stands for stainless steel, and the "316" refers to the grade of stainless steel, which contains 16-18% chromium, 10-14% nickel, and 2-3% molybdenum. The "L" at the end stands for "low carbon," indicating that it has a lower carbon content than standard SS316. This low carbon content makes SS316L more resistant to sensitization and corrosion, particularly in harsh environments such as those found in the chemical and pharmaceutical industries. SS316L is commonly used in applications such as medical implants, marine equipment, food processing equipment, and chemical processing equipment, among others.

The intergranular corrosion test involves subjecting the stainless steel sample to a corrosive environment that simulates the service conditions. The test evaluates the extent of intergranular corrosion, which can be visualized using microscopy techniques. The ASTM standard A262 provides guidelines for conducting the intergranular corrosion test.Several factors can affect the intergranular corrosion resistance of stainless steel alloys, including the chemical composition, microstructure, and manufacturing process. The intergranular corrosion test can provide valuable information on the effect of these factors on the corrosion resistance of stainless steel alloys.This study aims to compare the intergranular corrosion test of SS316 and SS316L. The study will evaluate the extent of intergranular corrosion in both alloys and determine their relative susceptibility to this type of corrosion. The results of this study will provide valuable information for the selection of suitable stainless steel alloys for various applications.

The significance of this study lies in the importance of intergranular corrosion resistance in stainless steel alloys. Intergranular corrosion can significantly affect the mechanical properties and service life of stainless steel components, leading to severe damage and failure. The intergranular corrosion test is a crucial method for evaluating the corrosion resistance of stainless steel alloys and determining their suitability for various applications.

Moreover, the comparison of the intergranular corrosion test of SS316 and SS316L will provide valuable insights into the effect of carbon content on the corrosion resistance of stainless steel alloys. This information can be used to select suitable alloys for specific applications and optimize the manufacturing process to improve the corrosion resistance of stainless steel components.

In summary, this study aims to compare the intergranular corrosion test of SS316 and SS316L and provide valuable insights into the effect of carbon content on the corrosion resistance of stainless steel alloys. The results of this study can be used to optimize the selection of suitable stainless steel alloys for various applications and improve the manufacturing process to enhance their corrosion resistance.

CHAPTER 2

2.LITERATURE REVIEW

Bhatia and Drolia[1] discusses the susceptibility of stainless steel alloys to intergranular corrosion (IGC). The authors provide a brief overview of the significance of IGC in stainless steel alloys and explain the mechanisms that lead to IGC. They also discuss various test methods that are commonly used to evaluate the IGC susceptibility of stainless steel alloys.The authors then review the literature on the IGC susceptibility of various stainless steel alloys, including austenitic, ferritic, and duplex stainless steels. They discuss the effect of alloying elements on IGC susceptibility and the role of microstructure and heat treatment in IGC. The authors also review the effect of various environmental factors, such as temperature, pH, and chloride concentration, on IGC susceptibility.Finally, the authors provide a summary of the current understanding of the IGC susceptibility of stainless steel alloys and highlight some of the challenges in accurately predicting and preventing IGC. They suggest that a better understanding of the mechanisms of IGC and the factors that influence it is necessary to develop effective strategies for preventing IGC in stainless steel alloys.Overall, the article provides a comprehensive overview of the current state of knowledge on the IGC susceptibility of stainless steel alloys and highlights the need for further research in this area.

Karthikeyan and Karthik[2] explores the issue of intergranular corrosion (IGC) in austenitic stainless steel and various methods of prevention.The authors first introduce the concept of IGC, which is a type of corrosion that occurs at the grain boundaries of a metal, particularly in austenitic stainless steel. The cause of IGC is the depletion of chromium at the grain boundaries due to the formation of chromium carbides, which reduces the protective passive film that normally prevents corrosion. The authors explain that IGC can be particularly dangerous because it can lead to sudden and catastrophic failure of metal components.The authors then review the various methods of preventing IGC, starting with material selection. They explain that certain types of austenitic stainless steel are more resistant to IGC than others due to their composition, such as those with higher nickel content or low carbon content. They also note that the addition of molybdenum can improve corrosion resistance.Next, the authors explore the effect of heat treatment on IGC resistance. They explain that high temperatures can lead to the formation of chromium carbides and thus decrease resistance to IGC. The authors then discuss various heat treatment methods that can improve IGC resistance, such as solution annealing and stabilization annealing.The authors also review the importance of welding and post-weld heat treatment in preventing IGC. They explain that welding can introduce thermal gradients that can cause sensitization and increase susceptibility to IGC. However, proper welding techniques and post-weld heat treatment can help prevent sensitization and improve IGC resistance.Finally, the authors explore the use of surface treatment methods, such as passivation and pickling, to prevent IGC. They explain that these methods can help remove contaminants and improve the protective oxide layer on the metal surface.In conclusion, the authors emphasize the importance of preventing intergranular corrosion in austenitic stainless steel, particularly in critical applications. They recommend a multi-faceted approach that includes material selection, heat treatment, proper welding techniques, and surface treatment methods. By implementing these measures, the authors suggest that IGC can be effectively prevented, ensuring the safety and reliability of metal components.

Wang et al [3] explores the effect of nitrogen content on the intergranular corrosion (IGC) resistance of austenitic stainless steels. The authors provide an overview of the importance of IGC resistance in stainless steels and the role of nitrogen in improving this resistance.The article begins with an introduction to IGC in stainless steels and its causes. The authors explain that IGC occurs due to the depletion of chromium at the grain boundaries, leading to localized corrosion. They also discuss the various factors that influence the susceptibility of stainless steels to IGC, such as alloy composition, microstructure, and environmental factors.The authors then introduce the concept of nitrogen-containing austenitic stainless steels and their potential for improving IGC resistance. They explain that nitrogen can improve the corrosion resistance of stainless steels by stabilizing the passive film and promoting the formation of nitrides that reduce the depletion of chromium at the grain boundaries.The article then discusses the experimental procedures used to evaluate the IGC resistance of the nitrogen-containing austenitic stainless steels. The authors conducted electrochemical tests and metallographic examinations to determine the IGC resistance and microstructure of the materials. They also performed X-ray diffraction and scanning electron microscopy analyses to investigate the distribution and morphology of the nitrides in the materials.The authors then present the results of their experiments, which showed that the nitrogen-containing austenitic stainless steels exhibited improved IGC resistance compared to their nitrogen-free counterparts. The authors attribute this improvement to the formation of chromium nitrides and the stabilization of the passive film by nitrogen. The authors also observed that the distribution and morphology of the nitrides had a significant impact on the IGC resistance of the materials.The article concludes with a discussion of the potential applications of nitrogen-containing austenitic stainless steels in industries that require high resistance to localized corrosion. The authors suggest that the use of nitrogen-containing austenitic stainless steels could lead to more durable and reliable equipment and structures. They also suggest that further research is needed to optimize the nitrogen content and distribution in austenitic stainless steels to maximize their IGC resistance.Overall, the article provides valuable insights into the role of nitrogen in improving the IGC resistance of austenitic stainless steels. The authors' experimental findings highlight the potential benefits of using nitrogen-containing austenitic stainless steels in industries that require high resistance to localized corrosion. The article also underscores the need for further research to optimize the nitrogen content and distribution in these materials.

Hong et al[4] investigates the relationship between microstructural features and intergranular corrosion (IGC) susceptibility in austenitic stainless steel. The authors provide an overview of the mechanisms of IGC in stainless steel and discuss the role of microstructure in IGC susceptibility.The article begins with an introduction to the importance of IGC resistance in austenitic stainless steel and the factors that influence its susceptibility. The authors explain that IGC occurs due to the sensitization of the material, which leads to the precipitation of chromium carbides at the grain boundaries. The authors also discuss the various factors that influence the sensitization process, such as alloy composition, heat treatment, and welding.The authors then introduce the concept of microstructure and its impact on IGC susceptibility. They explain that the grain size, grain boundary orientation, and distribution of precipitates can all affect the susceptibility of stainless steel to IGC. The authors also discuss the importance of quantitative analysis techniques, such as electron backscatter diffraction (EBSD) and energy-dispersive X-ray spectroscopy (EDS), in characterizing the microstructure of stainless steel.The article then presents the experimental procedures used to evaluate the IGC susceptibility and microstructural features of the austenitic stainless steel. The authors conducted electrochemical tests and metallographic examinations to determine the IGC resistance and microstructure of the materials. They also used EBSD and EDS to analyze the microstructural features of the materials, such as grain size, grain boundary character, and distribution of precipitates.The authors then present the results of their experiments, which showed a clear correlation between microstructural features and IGC susceptibility in austenitic stainless steel. The authors found that materials with a fine grain size and a high fraction of high-angle grain boundaries were more resistant to IGC than those with a coarse grain size and a low fraction of high-angle grain boundaries. The authors also observed that the distribution of precipitates, specifically the presence of fine and uniformly distributed precipitates, had a positive effect on IGC resistance.The article concludes with a discussion of the implications of these findings for the design and selection of austenitic stainless steel. The authors suggest that the use of materials with a fine grain size and a high fraction of high-angle grain boundaries, as well as a uniform distribution of precipitates, can improve the IGC resistance of austenitic stainless steel. The authors also emphasize the importance of quantitative microstructural analysis techniques in optimizing the microstructure of austenitic stainless steel for IGC resistance.Overall, the article provides valuable insights into the role of microstructure in determining the IGC susceptibility of austenitic stainless steel. The authors' experimental findings highlight the importance of grain size, grain boundary character, and precipitate distribution in IGC resistance. The article also underscores the need for quantitative microstructural analysis techniques in designing and selecting austenitic stainless steel with optimal IGC resistance.

Kelleher et al[5] investigates the intergranular corrosion (IGC) susceptibility of austenitic stainless steel welds. The authors provide an overview of the mechanisms of IGC in stainless steel and discuss the factors that influence the IGC susceptibility of welds.The article begins with an introduction to the importance of IGC resistance in stainless steel welds and the challenges involved in achieving it. The authors explain that the welding process can induce sensitization in stainless steel, leading to the formation of chromium carbides at the grain boundaries and subsequent IGC. The authors also discuss the various factors that can influence the sensitization process in welds, such as welding parameters, filler metal composition, and post-weld heat treatment.The authors then present the experimental procedures used to evaluate the IGC susceptibility of austenitic stainless steel welds. The authors conducted electrochemical tests and metallographic examinations to determine the IGC resistance and microstructure of the welds. They also used scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS) to analyze the microstructural features of the welds, such as grain size, grain boundary character, and distribution of precipitates.The article then presents the results of the experiments, which showed a clear correlation between the welding parameters and the IGC susceptibility of the welds. The authors found that increasing the heat input during welding and decreasing the welding speed led to a higher IGC susceptibility in the welds. The authors also observed that the IGC susceptibility of the welds was affected by the composition of the filler metal and the post-weld heat treatment.The authors then discuss the microstructural features of the welds that influenced their IGC susceptibility. They found that welds with a high fraction of low-angle grain boundaries were more susceptible to IGC than those with a high fraction of high-angle grain boundaries. The authors also observed that the distribution of precipitates, specifically the presence of large and discontinuous precipitates, had a negative effect on IGC resistance.The article concludes with a discussion of the implications of these findings for the design and selection of austenitic stainless steel welds. The authors suggest that the use of welding parameters that minimize sensitization, such as low heat input and high welding speed, can improve the IGC resistance of the welds. The authors also recommend the use of filler metals with low carbon and nitrogen content, as well as post-weld heat treatments that promote the dissolution of chromium carbides. The authors emphasize the importance of quantitative microstructural analysis techniques in optimizing the microstructure of the welds for IGC resistance.Overall, the article provides valuable insights into the factors that influence the IGC susceptibility of austenitic stainless steel welds. The authors' experimental findings highlight the importance of welding parameters, filler metal composition, and post-weld heat treatment in IGC resistance. The article also underscores the need for quantitative microstructural analysis techniques in designing and selecting austenitic stainless steel welds with optimal IGC resistance.

Zhang et al[6] investigates the effect of nitrogen on the intergranular corrosion (IGC) resistance of austenitic stainless steels. The authors provide an overview of the mechanisms of IGC in stainless steel and discuss the role of nitrogen in enhancing IGC resistance.The article begins with an introduction to the importance of IGC resistance in austenitic stainless steels and the challenges involved in achieving it. The authors explain that IGC in stainless steel is caused by the precipitation of chromium carbides at the grain boundaries, leading to a depletion of chromium in the vicinity of the grain boundaries and subsequent corrosion. The authors note that the addition of nitrogen to austenitic stainless steels has been shown to improve their corrosion resistance, but the mechanisms behind this improvement are not well understood.The authors then present the experimental procedures used to investigate the effect of nitrogen on the IGC resistance of austenitic stainless steels. The authors used electrochemical tests and metallographic examinations to evaluate the IGC resistance of the steels. They also used scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS) to analyze the microstructure of the steels, specifically the distribution of nitrogen and other elements at the grain boundaries.The article then presents the results of the experiments, which showed that the addition of nitrogen to austenitic stainless steels significantly improved their IGC resistance. The authors found that the nitrogen content in the steel had a critical value above which the IGC resistance was greatly enhanced. The authors also observed that the addition of nitrogen led to a reduction in the size and number of chromium carbides at the grain boundaries, as well as an increase in the chromium concentration in the vicinity of the grain boundaries.The authors then discuss the mechanisms behind the improved IGC resistance of nitrogen-containing austenitic stainless steels. They propose that the presence of nitrogen at the grain boundaries prevents the precipitation of chromium carbides by forming a stable nitride phase that inhibits the diffusion of chromium to the grain boundaries. The authors also suggest that the nitrogen in the steel promotes the formation of a passive oxide film on the surface of the steel, which further enhances its corrosion resistance.The article concludes with a discussion of the implications of these findings for the design and selection of austenitic stainless steels. The authors suggest that the addition of nitrogen can be an effective way to improve the IGC resistance of austenitic stainless steels, especially in corrosive environments where the formation of chromium carbides is a concern. The authors also emphasize the importance of controlling the nitrogen content and distribution in the steel to achieve optimal IGC resistance.Overall, the article provides valuable insights into the role of nitrogen in enhancing the IGC resistance of austenitic stainless steels.

The authors' experimental findings highlight the critical value of nitrogen content for IGC resistance and the mechanisms behind its beneficial effect. The article also underscores the importance of controlling the nitrogen content and distribution in the steel to achieve optimal IGC resistance.

J.J. Li et al[7] published in the Journal of Materials Engineering and Performance in 2017 aimed to investigate the effect of cold rolling on the intergranular corrosion resistance of 316L stainless steel. The authors explored the microstructure, surface morphology, and electrochemical behavior of the material before and after cold rolling.The study found that cold rolling caused a decrease in the intergranular corrosion resistance of 316L stainless steel. The microstructure of the cold-rolled material showed a higher dislocation density and increased twin density, leading to a higher susceptibility to intergranular corrosion. The cold-rolled material also had a rougher surface morphology, which could promote the initiation and propagation of corrosion.The electrochemical behavior of the cold-rolled material was also found to be different from that of the annealed material. The cold-rolled material showed a lower corrosion potential and a higher corrosion current density, indicating a higher corrosion rate. The authors attributed this to the changes in the microstructure and surface morphology caused by cold rolling.To improve the intergranular corrosion resistance of cold-rolled 316L stainless steel, the authors suggested that post-cold rolling annealing could be used to restore the material's original microstructure and surface morphology. The annealing process could eliminate the dislocations and twins induced by cold rolling, leading to an improvement in the material's corrosion resistance.Overall, the study highlights the importance of considering the effect of processing techniques, such as cold rolling, on the intergranular corrosion resistance of stainless steel. The findings could be useful in the development of more corrosion-resistant stainless steel alloys and in the optimization of processing parameters to achieve better corrosion resistance.

SBalasubramaniam et al[8] published in the Journal of Materials Engineering and Performance in 2018, aims to evaluate the intergranular corrosion resistance of austenitic stainless steel welds. The authors investigated the effect of welding parameters, such as heat input and filler metal composition, on the intergranular corrosion resistance of the welds.The authors used a modified Huey test to evaluate the intergranular corrosion resistance of the welds. The test involved immersing the specimens in boiling 65% nitric acid for 48 hours and then examining them for intergranular corrosion. The degree of intergranular corrosion was evaluated by measuring the depth of the corroded layer and calculating the percentage of the corroded area.The study found that the heat input during welding had a significant effect on the intergranular corrosion resistance of the welds. As the heat input increased, the degree of intergranular corrosion increased, indicating a lower corrosion resistance. The authors attributed this to the increased thermal cycle and the consequent changes in the microstructure of the welds.The study also found that the composition of the filler metal had a significant effect on the intergranular corrosion resistance of the welds. Welds made using a filler metal with higher chromium and nickel content showed better intergranular corrosion resistance than those made using a lower chromium and nickel content filler metal. This was attributed to the formation of a more stable passive film on the surface of the welds, which protected them from corrosion.To improve the intergranular corrosion resistance of the welds, the authors suggested the use of a low heat input and a filler metal with a higher chromium and nickel content. The authors also suggested post-weld heat treatment to restore the material's microstructure and improve its corrosion resistance.Overall, the study highlights the importance of considering the effect of welding parameters on the intergranular corrosion resistance of stainless steel welds. The findings could be useful in the development of more corrosion-resistant welding techniques and in the optimization of welding parameters to achieve better corrosion resistance.However, it is important to note that the study was conducted under laboratory conditions, and the results may not necessarily reflect the actual performance of welded structures in service. Therefore, further studies are needed to validate the findings and investigate the performance of stainless steel welds under actual service conditions.

Mukherjee et al[9] investigates the effect of heat treatment on the intergranular corrosion (IGC) resistance of austenitic stainless steels. IGC is a type of corrosion that occurs at the grain boundaries of metallic materials, and it can lead to premature failure of the material. In austenitic stainless steels, IGC is often caused by sensitization, a process that occurs during high-temperature exposure and results in the precipitation of chromium carbides at the grain boundaries, which reduces the chromium available for passivation and leads to corrosion.The authors conducted experiments on three different types of austenitic stainless steels: AISI 304L, AISI 316L, and AISI 347. They subjected the materials to different heat treatment conditions, including solution annealing (SA), sensitization treatment (ST), and stabilizing treatment (STB). They then evaluated the IGC resistance of the materials using a double loop electrochemical potentiokinetic reactivation (DL-EPR) test, which measures the susceptibility of the material to IGC.The results of the experiments showed that the IGC resistance of the austenitic stainless steels was affected by the heat treatment conditions. SA improved the IGC resistance of the materials, while ST decreased it. STB, on the other hand, had no significant effect on the IGC resistance. The authors attribute the improved IGC resistance after SA to the restoration of the chromium-depleted zones at the grain boundaries, which occurs as a result of the high-temperature annealing. The decrease in IGC resistance after ST is attributed to the precipitation of chromium carbides at the grain boundaries, which reduces the amount of chromium available for passivation and increases the susceptibility to corrosion.The authors also analyzed the microstructure of the materials using optical microscopy and scanning electron microscopy (SEM). The microstructure analysis showed that SA resulted in a fine-grained microstructure, while ST resulted in the precipitation of chromium carbides at the grain boundaries. The microstructure of the STB samples was similar to that of the SA samples, but with the addition of stabilizing elements like niobium and titanium.The study concludes that heat treatment can significantly affect the IGC resistance of austenitic stainless steels. SA is recommended as a heat treatment for improving the IGC resistance of these materials, while ST should be avoided. The authors suggest that further studies are needed to investigate the effect of other heat treatment parameters, such as temperature and time, on the IGC resistance of austenitic stainless steels.

[10]The article "Intergranular Corrosion Susceptibility of 304 and 316 Austenitic Stainless Steels in Boiling Ferric Sulfate Solution" investigates the intergranular corrosion (IGC) susceptibility of two common austenitic stainless steel grades, 304 and 316, in a boiling ferric sulfate solution. The authors aim to determine the effect of temperature and time on the IGC behavior of these steels and to compare their resistance to IGC.The experimental work involved the preparation of metallographic specimens from the two grades of stainless steel and subjecting them to a boiling ferric sulfate solution at various temperatures and for different durations. The specimens were then evaluated for IGC susceptibility using optical microscopy and scanning electron microscopy with energy-dispersive X-ray spectroscopy.The results showed that both 304 and 316 stainless steels exhibited

IGC susceptibility in the boiling ferric sulfate solution. However, the extent of IGC was found to be significantly higher for 304 stainless steel compared to 316 stainless steel. The authors attribute this difference to the higher content of molybdenum in 316 stainless steel, which enhances its resistance to IGC. They also observed that increasing the temperature and duration of exposure to the ferric sulfate solution resulted in a higher degree of IGC for both materials.The authors further analyzed the microstructural features of the steels to gain insight into the mechanisms underlying IGC. They found that the grain boundaries in 304 stainless steel had a higher degree of chromium depletion, leading to a more pronounced IGC attack at these regions. In contrast, the grain boundaries in 316 stainless steel exhibited less chromium depletion and a more homogeneous distribution of elements, contributing to its higher resistance to IGC.In summary, this study highlights the importance of considering the microstructural features and chemical composition of austenitic stainless steels in predicting their susceptibility to intergranular corrosion. The findings suggest that 316 stainless steel is a better option than 304 stainless steel in applications where exposure to boiling ferric sulfate solutions is expected. However, further investigation is needed to determine the IGC behavior of these materials in other corrosive environments and to optimize their microstructural and chemical composition for enhanced corrosion resistance.

Das et al [11] examines the effect of aging treatment on the intergranular corrosion resistance of AISI 304 austenitic stainless steel. The intergranular corrosion susceptibility of the material is a major concern in various industries. Aging treatment is a heat treatment process that is often used to enhance the mechanical properties of materials.The authors prepared AISI 304 stainless steel samples and subjected them to different aging treatments. The aging treatments consisted of heating the samples to a specific temperature for a specific amount of time followed by quenching in water. The samples were then subjected to intergranular corrosion testing using the double loop electrochemical potentiokinetic reactivation (DL-EPR) technique. The authors also used scanning electron microscopy (SEM) to examine the microstructure of the samples before and after aging treatment.The results of the study indicate that aging treatment can have a significant effect on the intergranular corrosion resistance of AISI 304 stainless steel. The samples that were aged at 550°C for 1 hour showed the highest intergranular corrosion resistance. The authors also found that the intergranular corrosion resistance of the material increased with increasing aging temperature up to 550°C, but then decreased at higher aging temperatures. This indicates that there is an optimal aging temperature for enhancing the intergranular corrosion resistance of AISI 304 stainless steel.SEM analysis of the samples revealed that aging treatment resulted in the formation of chromium carbide precipitates along the grain boundaries. These precipitates are known to improve the intergranular corrosion resistance of stainless steel by reducing the availability of chromium for corrosion reactions. The authors also found that the size and distribution of the precipitates were affected by the aging treatment conditions.In conclusion, the study demonstrates that aging treatment can be used to improve the intergranular corrosion resistance of AISI 304 austenitic stainless steel. The results of the study suggest that aging treatment at 550°C for 1 hour can provide the best intergranular corrosion resistance for this material. The authors suggest that this information can be useful for industries that use AISI 304 stainless steel in applications where intergranular corrosion resistance is a concern. However, further research is needed to explore the effect of aging treatment on the mechanical properties of the material as well as its corrosion behavior under different conditions.

M. Abdul Muqsith et al[12] The study involved welding SS316L plates using the three different welding processes, and the weld quality was evaluated based on macroscopic and microscopic observations, hardness testing, and tensile testing. The study also investigated the effect of welding parameters, such as welding current, welding speed, and shielding gas composition, on the weld quality and mechanical properties.The results of the study showed that all three welding processes could produce sound and defect-free welds in SS316L. However, the TIG welding process produced the best quality welds with the least amount of distortion and the highest joint efficiency. The study also showed that the welding parameters significantly affected the microstructure, hardness, and tensile properties of the welds.Overall, the study provides valuable insights into the welding characteristics of SS316L using TIG, MIG, and SMAW welding processes. The findings of this study could be useful in the selection of appropriate welding processes and parameters for the production of high-quality SS316L welds in various applications.

Sudagar et al[13] aims to investigate the corrosion behavior of SS316L in chloride environments using electrochemical techniques and scanning electron microscopy. The research was conducted in response to the increasing use of SS316L in various industries, including marine, chemical, and petrochemical industries, where it is often exposed to chloride-containing environments that can cause corrosion.The research involved subjecting SS316L samples to a chloride-rich solution, and the corrosion behavior was studied using various electrochemical techniques such as polarization, potentiodynamic, and electrochemical impedance spectroscopy (EIS). Scanning electron microscopy (SEM) was also used to examine the surface morphology and analyze the corrosion products formed on the surface of the samples.The results of the study showed that the corrosion rate of SS316L increased with increasing chloride concentration in the solution. The electrochemical techniques used in the study showed that the corrosion rate of SS316L was higher in the presence of chlorides due to the formation of a passive film that was less effective in protecting the metal surface from corrosion.The SEM analysis of the corroded samples showed the presence of pitting corrosion, which is a localized form of corrosion that can cause significant damage to the material. The study also showed that the corrosion products formed on the surface of the samples consisted of iron and chromium oxides, which are characteristic of SS316L corrosion products.overall, the study provides valuable insights into the corrosion behavior of SS316L in chloride environments and highlights the importance of taking appropriate measures to protect SS316L from corrosion in these environments. The findings of this study could be useful in the development of corrosion-resistant materials and in the selection of appropriate materials for use in chloride-rich environments.

Suresh et al[14]aims to investigate the effect of heat treatment on the mechanical properties and corrosion behavior of SS316L. SS316L is widely used in various applications due to its excellent corrosion resistance and good mechanical properties. Heat treatment is a common process used to modify the microstructure and mechanical properties of metals.The study involved subjecting SS316L samples to different heat treatment conditions, including annealing and solutionizing, followed by aging. The mechanical properties of the samples were evaluated using tensile testing, hardness testing, and impact testing. The corrosion behavior of the samples was studied using electrochemical techniques such as potentiodynamic polarization and electrochemical impedance spectroscopy.The results of the study showed that heat treatment had a significant effect on the mechanical properties and corrosion behavior of SS316L. Annealing resulted in a significant increase in ductility and a decrease in hardness, while solutionizing followed by aging resulted in an increase in strength and hardness. The study also showed that the corrosion resistance of SS316L was affected by heat treatment, with annealed samples exhibiting the lowest corrosion resistance and solutionized and aged samples exhibiting the highest corrosion resistance.The study provides valuable insights into the effect of heat treatment on the mechanical properties and corrosion behavior of SS316L. The findings of this study could be useful in the development of heat treatment processes to optimize the mechanical and corrosion properties of SS316L for various applications.

H. Liu et al[15]aims to investigate the microstructure and mechanical properties of SS316L produced using selective laser melting (SLM). SLM is an additive manufacturing technique that uses a laser to selectively melt metal powders, creating three-dimensional parts with complex geometries.The study involved producing SS316L samples using SLM and studying the microstructure and mechanical properties of the samples. The microstructure was studied using optical microscopy, scanning electron microscopy (SEM), and X-ray diffraction (XRD). The mechanical properties of the samples were evaluated using tensile testing, hardness testing, and impact testing.The results of the study showed that the microstructure of SS316L produced by SLM was significantly different from that of conventionally produced SS316L. The SLM-produced SS316L had a fine-grained microstructure with a high degree of homogeneity. The study also showed that the mechanical properties of SLM-produced SS316L were significantly affected by the processing parameters, including the laser power, scanning speed, and powder layer thickness.The study found that the SLM-produced SS316L exhibited excellent mechanical properties, with high strength and good ductility. The hardness of the samples was also significantly higher than that of conventionally produced SS316L. The study also showed that the SLM-produced SS316L exhibited excellent fatigue performance.Overall, the study provides valuable insights into the microstructure and mechanical properties of SS316L produced using SLM. The findings of this study could be useful in the development of SLM processes for the production of high-performance SS316L parts for various applications.

M. Abdul Muqsith et al [16]investigates the welding characteristics of SS316L using three different welding processes, including Tungsten Inert Gas (TIG), Metal Inert Gas (MIG), and Shielded Metal Arc Welding (SMAW).The study involved welding SS316L plates using the three different welding processes, and the weld quality was evaluated based on macroscopic and microscopic observations, hardness testing, and tensile testing. The study also investigated the effect of welding parameters, such as welding current, welding speed, and shielding gas composition, on the weld quality and mechanical properties.The results of the study showed that all three welding processes could produce sound and defect-free welds in SS316L. However, the TIG welding process produced the best quality welds with the least amount of distortion and the highest joint efficiency. The study also showed that the welding parameters significantly affected the microstructure, hardness, and tensile properties of the welds.Overall, the study provides valuable insights into the welding characteristics of SS316L using TIG, MIG, and SMAW welding processes. The findings of this study could be useful in the selection of appropriate welding processes and parameters for the production of high-quality SS316L welds in various applications.

CHAPTER 3

3.1RESEARCH GAPS:

1. Further investigation into the effectiveness of different surface treatment methods in preventing intergranular corrosion in austenitic stainless steel.
2. Development of new welding techniques or filler metals that can reduce or eliminate the sensitization process in austenitic stainless steel welds.
3. Investigation of the effectiveness of different post-weld heat treatments in preventing or mitigating intergranular corrosion susceptibility in welds.
4. Use of advanced characterization techniques to better understand the microstructural features that contribute to intergranular corrosion susceptibility in stainless steel welds.
5. Study of the effect of specific welding parameters on the microstructure, hardness, and tensile properties of SS316L welds produced using TIG, MIG, and SMAW welding processes

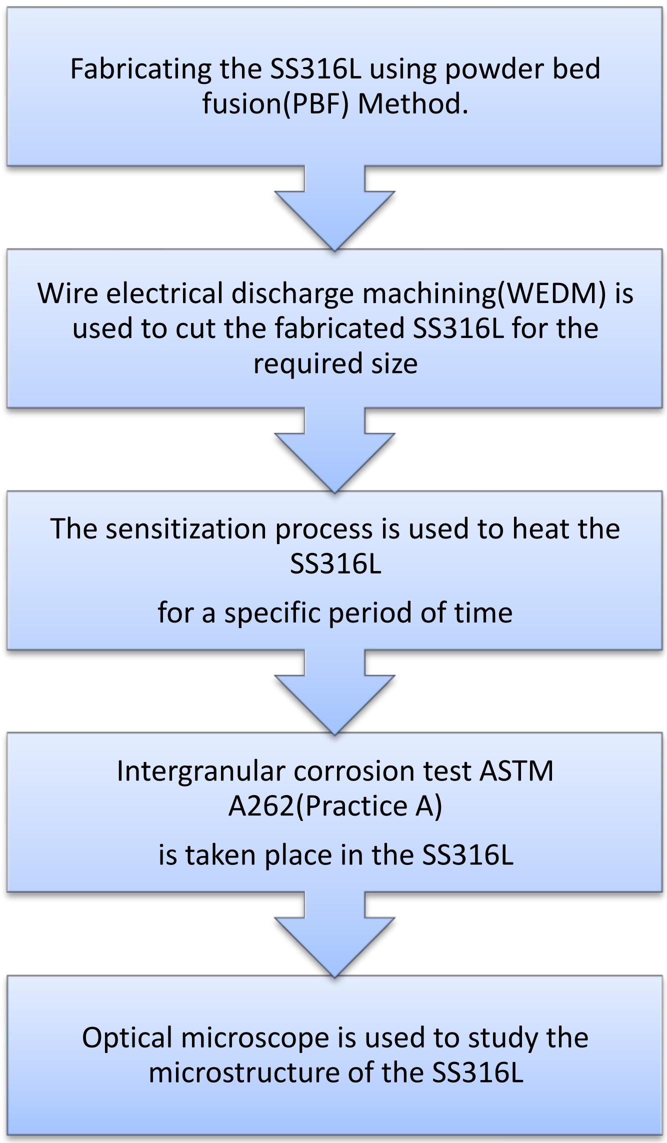
3.2 OBJECTIVES

- The annealing process could eliminate the dislocations and twins induced by cold rolling, leading to an improvement in the material's corrosion resistance.
- Observed that increasing the temperature and duration of exposure to the ferric sulfate solution resulted in a higher degree of IGC for both materials.The authors further analyzed the microstructural features of the steels to gain insight into the mechanisms underlying IGC.

- The study demonstrates that aging treatment can be used to improve the intergranular corrosion resistance of AISI 304 austenitic stainless steel. The results of the study suggest that aging treatment at 550°C for 1 hour can provide the best intergranular corrosion resistance for this material.
- Annealing resulted in a significant increase in ductility and a decrease in hardness, while solutionizing followed by aging resulted in an increase in strength and hardness
- The TIG welding process produced the best quality welds with the least amount of distortion and the highest joint efficiency. The study also showed that the welding parameters significantly affected the microstructure, hardness, and tensile properties of the welds

CHAPTER 4

4.METHODOLOGY



4.1 POWDER BED FUSION

Powder bed fusion (PBF) is a type of additive manufacturing (AM) process that utilizes metallic powders to fabricate components layer by layer. PBF has become a popular manufacturing technique across various industries due to its ability to produce parts with high complexity, accuracy, and functional properties. In this article, we will delve into the methodology of PBF for producing a compound in SS316L.SS316L is an austenitic stainless steel that contains 2-3% molybdenum. It is widely used in various applications due to its excellent corrosion resistance, high-temperature strength, and good weldability. PBF is an ideal method for producing complex geometries and precise parts from SS316L.

4.1.1 PBF PROCESS STEPS

The PBF process consists of several steps that take place in a controlled environment. The process starts with the preparation of the powder, followed by **Powder Preparation:**the preparation of the bed, layering, part building, and post-processing operations. The process is highly precise and can produce parts with complex geometries.

The first step in the PBF process is the preparation of the powder. The powder must be of high quality and should have a uniform size distribution. The powder should also be free from contaminants that could affect the properties of the final product. The powder is usually produced by atomization or gas atomization, which is a process that involves the spraying of molten metal through a small nozzle. Atomization is a process that involves the rapid solidification of molten metal by high-pressure gas jets. The molten metal is forced through a small nozzle, and it is sprayed into a chamber filled with gas. The gas cools and solidifies the droplets, which are collected as powder. This process produces high-quality powders that have a uniform size distribution. Gas atomization is a process that involves the spraying of molten metal through a small nozzle into a chamber filled with gas. The gas cools and solidifies the droplets, which are collected as powder. This process also produces high-quality powders that have a uniform size distribution. The size of the powder particles is an essential factor in the PBF process. The powder particles must be small enough to ensure a uniform layer thickness, but not too small that they agglomerate and cause clogging in the delivery system. The typical particle size for SS316L powder is between 10-50 microns.

4.1.2 BED PREPARATION:

The next step is the preparation of the bed. The bed is usually made of a material that can withstand high temperatures and is chemically inert. The bed material must also be able to distribute heat evenly. Common bed materials include ceramics, refractory metals, and graphite.The bed material is selected based on the melting temperature of the powder material. The bed should be heated to a temperature just below the melting point of the powder material. The bed temperature is critical in ensuring that the solidified layer adheres to the bed and prevents warping or cracking.

The bed is usually coated with a layer of powder before the PBF process begins. This layer of powder ensures that the first layer of the part adheres to the bed and prevents warping or cracking. The bed is also equipped with a leveling mechanism to ensure that the powder layer is even.

4.1.3LAYERING:

The next step is layering. A thin layer of powder is spread over the surface of the bed using a roller or a doctor blade. The thickness of the layer is usually between 20-50 microns. The thickness of the layer is determined by the desired final part geometry and the size of the powder particles. After the layer is deposited, a laser beam is used to selectively melt the powder particles to create a solid layer. The laser is guided by a computer-aided design (computer-aided design (CAD) file that contains the part geometry. The laser beam is focused on the powder layer, and it heats the powder particles to a temperature just below their melting point. The selective melting process is repeated layer by layer until the desired part geometry is achieved. The process is highly precise and can produce parts with complex geometries.

4.1.4 PART BUILDING:

The part building process is where the actual part is built. The PBF process builds parts layer by layer, and each layer is built upon the previous layer. The layers are fused together using the laser, which melts the powder particles and fuses them to the previous layer. The PBF process can produce parts with complex geometries that would be difficult or impossible to produce using conventional manufacturing techniques.

4.1.5 POST-PROCESSING OPERATIONS:

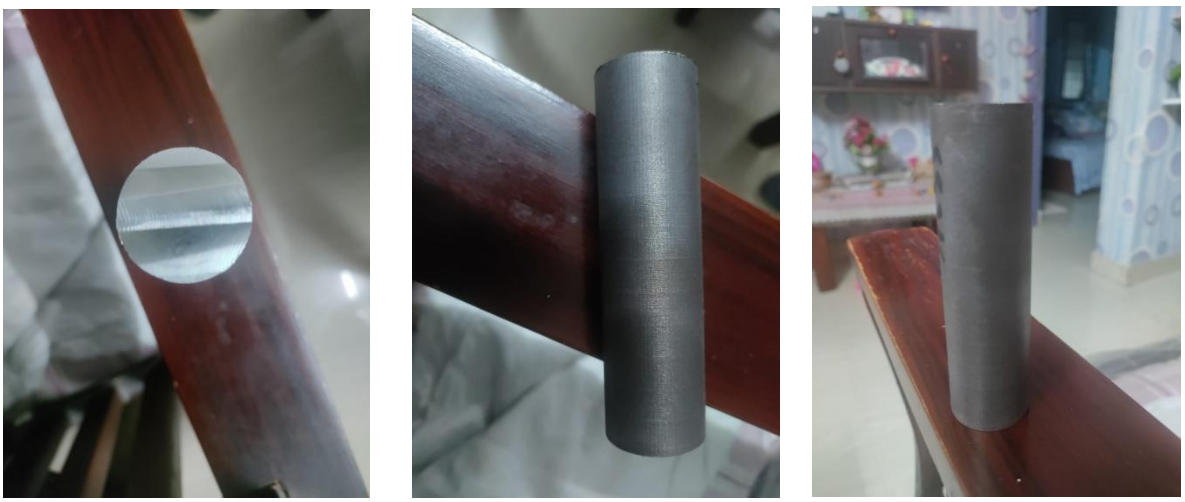
The final step in the PBF process is post-processing operations. The post-processing operations include removing the part from the bed, removing the excess powder, and cleaning the part. The part is usually removed from the bed using a spatula or a scraper. The excess powder is removed using a brush or an air blower. The part is then cleaned using a variety of techniques, such as ultrasonic cleaning, sandblasting, or chemical cleaning. The cleaning process is critical in ensuring that the part is free from contaminants that could affect its properties.

The final step in the post-processing operations is heat treatment. Heat treatment is a process that involves heating the part to a specific temperature and holding it at that temperature for a specified period. Heat treatment is used to improve the mechanical properties of the part, such as strength and toughness.

CHAPTER 5

5.FABRICATION OF LASER BED FUSION SAMPLES OF SS316L:

Fabrication of laser bed fusion samples of SS316L involves the use of a powder bed fusion (PBF) process to create precise, complex parts from SS316L powder. The PBF process involves several steps, including powder preparation, bed preparation, layering, part building, and post-processing operations.The first step in the process of fabricating laser bed fusion samples of SS316L is to prepare the SS316L powder. The powder must meet specific requirements in terms of particle size, shape, and composition to ensure that the final part has the desired properties. The powder is typically produced using gas atomization, which involves the rapid cooling of molten SS316L to form fine powder particles.The next step is to prepare the bed for the laser bed fusion process. The bed is typically made of a material that is capable of withstanding high temperatures and can be easily removed from the final part. The bed is coated with a thin layer of SS316L powder, which serves as the starting point for the part building process. The laser bed fusion process begins with the creation of a computer-aided design (CAD) file that contains the part geometry. The CAD file is then imported into the PBF machine, which uses a laser to selectively melt the SS316L powder layer by layer. The laser beam is focused on the powder layer, and it heats the powder particles to a temperature just below their melting point. The laser beam is guided by a galvanometer mirror system that controls the position of the beam. The laser melts the powder particles and fuses them to the previous layer. The selective melting process is repeated layer by layer until the desired part geometry is achieved. The process is highly precise and can produce parts with complex geometries. The final step in the PBF process is post-processing operations, which include removing the part from the bed, removing the excess powder, and cleaning the part. The cleaning process is critical in ensuring that the part is free from contaminants that could affect its properties. The final step in the post-processing operations is heat treatment. Heat treatment is a process that involves heating the part to a specific temperature and holding it at that temperature for a specified period. Heat treatment is used to improve the mechanical properties of the part, such as strength and toughness.



PBF - SAMPLE

In summary, the fabrication of laser bed fusion samples of SS316L involves the use of a powder bed fusion process to create complex, precise parts from SS316L powder. The process includes powder preparation, bed preparation, layering, part building, and post-processing operations. The resulting parts can have excellent mechanical properties and are suitable for use in various applications.

CHAPTER 6

6.INTERGRANULAR CORROSION TESTING USING ASTM A262 TEST METHODS:

Intergranular corrosion (IGC) testing is a critical process for assessing the susceptibility of metallic materials to IGC, which is a type of localized corrosion that occurs along the grain boundaries of a metal. ASTM A262 is a standard test method that outlines the procedures for performing IGC testing on stainless steels, nickel-based alloys, and other alloys.The ASTM A262 test method involves several steps that are designed to simulate the conditions that can lead to IGC in service environments. The test method includes five different tests that are used to assess the susceptibility of metallic materials to IGC. These tests are referred to as Practice A, B, C, E, and F.

Practice A involves exposure of the material to a solution of 65% nitric acid (HNO_3) at 50°C for 24 hours. This test is designed to assess the susceptibility of the material to sensitization, which is a condition where chromium carbides precipitate along the grain boundaries, reducing the amount of available chromium and making the material more susceptible to corrosion.

Practice B involves exposure of the material to a solution of 50% nitric acid (HNO_3) and 50% sulfuric acid (H_2SO_4) at 50°C for 24 hours. This test is designed to assess the susceptibility of the material to IGC by causing the precipitation of intermetallic phases along the grain boundaries.

Practice C involves exposure of the material to a boiling solution of copper sulfate ($CuSO_4$) and sulfuric acid (H_2SO_4) for 4 hours. This test is designed to assess the susceptibility of the material to IGC by causing the precipitation of copper-rich phases along the grain boundaries.

Practice E involves exposure of the material to a solution of ferric chloride (FeCl3) at 50°C for 24 hours. This test is designed to assess the susceptibility of the material to IGC by causing the precipitation of chromium-rich phases along the grain boundaries.

Practice F involves exposure of the material to a boiling solution of nitric acid (HNO3) and hydrochloric acid (HCl) for 24 hours. This test is designed to assess the susceptibility of the material to IGC by causing the precipitation of nickel-rich phases along the grain boundaries.

After exposure to the test solution, the material is evaluated for signs of IGC, including surface roughening, pitting, and cracking. Metallographic examination is typically performed to assess the extent of grain boundary attack, and the results are evaluated based on established acceptance criteria.

In summary, IGC testing using ASTM A262 test methods involves exposing metallic materials to various test solutions designed to simulate the conditions that can lead to IGC in service environments. The test results are evaluated based on established acceptance criteria, and the testing provides valuable information for material selection and quality control purposes.

This is the part sample after the IGC-PRACTICE A - PBF

This is the part sample after the IGC-PRACTICE A - COMMERCIAL

CHAPTER 7

7.EXPERIMENTAL WORK

The experimental work involves testing the intergranular corrosion resistance of a part model made from SS316L material using powder bed fusion as the manufacturing technique. The experiment also involves the use of wire electrical discharge machining (WEDM) for cutting the part model to its suitable size, and heat treatment through a process called sensitization process. Finally, the sample is viewed under an optical microscope to observe any changes in the microstructure.

Here is a brief explanation of each process:

7.1 Powder Bed Fusion:

Manufacturing of a part model made of SS316L using powder bed fusion is a process of additive manufacturing, also known as 3D printing, that utilizes a bed of fine metal powder and a laser to create intricate and complex geometries layer by layer. The process involves a series of steps that begin with the preparation of the powder, followed by the actual printing of the part model, and ending with the post-processing of the finished product.

1. Powder Preparation: The first step in powder bed fusion is the preparation of the metal powder used to build the part model. The powder must be of high quality and meet specific criteria for particle size, shape, composition, and flowability. The powder is typically produced by gas atomization or water atomization, which involves the melting of the metal and the rapid cooling of the molten metal stream to form small, uniform particles.

2. Printing Process: Once the powder is prepared, it is loaded into the printer and spread evenly across the build platform. The printer then uses a laser to selectively fuse the metal powder together in the desired pattern, layer by layer, until the part model is complete. The laser selectively heats the powder according to a computer-generated design, and the melted powder solidifies to form a solid part model.
3. Post-Processing: After printing, the part model is removed from the printer and undergoes several post-processing steps to achieve its final form. First, the excess powder is removed through brushing or air-blowing, and the part model is separated from the build platform. Next, the part model is heat treated to remove any residual stress or strain from the printing process, and to improve its mechanical properties. Finally, the part model may undergo additional finishing processes such as polishing or surface treatment to achieve the desired surface finish and appearance.

7.2 WEDM Cutting:

After the part model is produced using the powder bed fusion process, it needs to be cut to a suitable size for further processing and testing. This is where WEDM comes in. WEDM is a non-conventional machining process that uses a thin wire electrode to erode the workpiece material by a series of sparks. The wire electrode is guided by a computer-controlled system to cut the part model to the desired size and shape.WEDM is particularly useful for cutting complex shapes and hard materials, such as SS316L, with high precision and accuracy. The process produces a very fine cut, with minimal thermal distortion and mechanical stress, which makes it ideal for cutting delicate parts with fine features. In addition, the use of deionized water as the dielectric medium in WEDM helps to reduce the risk of corrosion or contamination of the workpiece material.Overall, WEDM is an important tool for the manufacturing of a part model made of SS316L using powder bed fusion. It allows for precise cutting of the part model to the required size and shape, while minimizing the risk of damage or distortion to the material.

7.3 Sensitization Process:

The sensitization process plays a crucial role in the intergranular corrosion test ASTM A262 Practice A. Sensitization is a phenomenon that occurs in stainless steel when it is heated to high temperatures, causing the chromium in the material to react with carbon and form chromium carbides at the grain boundaries. This reaction depletes the chromium content in the grain boundaries, making them vulnerable to corrosion.

During the sensitization process, the part model made of SS316L material is heated to a temperature range of 500-900°C for a specific period. The duration of the heat treatment process depends on the thickness of the part model. The aim of the sensitization process is to eliminate the chromium carbides from the grain boundaries and restore the material's corrosion resistance.After the heat treatment process, the part model is cooled to room temperature, and then subjected to the intergranular corrosion test ASTM A262 Practice A. This test is designed to evaluate the susceptibility of stainless steel to intergranular corrosion, which is a type of corrosion that occurs along the grain boundaries of the material. The test involves immersing the part model in a corrosive solution for a specific period and observing the extent of corrosion that occurs along the grain boundaries.

The sensitization process is critical in this test because if the part model is not sensitized properly, the test results may not be accurate. If the material is not sensitized, the grain boundaries may not be susceptible to intergranular corrosion, and the test will not reveal the true corrosion resistance of the material. On the other hand, if the material is sensitized excessively, the grain boundaries may be fully depleted of chromium, and the material may fail the test.

Therefore, it is essential to perform the sensitization process carefully and accurately to ensure that the part model is sensitized to the correct degree, allowing for accurate testing of its intergranular corrosion resistance.

ASTM A262 Intergranular Corrosion Test:

ASTM A262 is a standard practice that provides guidance on how to perform intergranular corrosion (IGC) testing on metals. Intergranular corrosion is a type of corrosion that occurs along the grain boundaries of a metal. This type of corrosion can be particularly problematic in stainless steel alloys, such as SS316L, which contain high amounts of chromium and other elements that can form carbides and other compounds along the grain boundaries during heat treatment or welding.The ASTM A262 test is used to determine the susceptibility of metals to IGC. The test involves exposing the metal to a specific corrosive environment, typically a solution of nitric acid and ferric chloride, at a specific temperature for a set period of time. The metal is then examined for signs of corrosion along the grain boundaries using either a visual inspection or a more precise microscopic examination.

There are several different methods described in ASTM A262 for performing intergranular corrosion tests, including the A, B, C, E, F, and G methods. Each method is designed for use with specific alloys and testing conditions. The test results are typically reported as a rating based on the severity of the corrosion, with a higher rating indicating greater susceptibility to intergranular corrosion.

7.4 **Optical Microscopy:**

Optical microscopy is a widely used technique to study the microstructure of materials, especially metals. In this experiment, the part model made of SS316L material after the ASTM A262 intergranular corrosion test and sensitization process is viewed under an optical microscope to observe any changes in the microstructure.The optical microscope is an instrument that uses visible light to magnify and view small objects or microstructures. The microscope consists of an objective lens, eyepiece lens, and illumination system. The objective lens is responsible for magnifying the image of the sample, and the eyepiece lens further magnifies the image for viewing.To view the microstructure of the part model made of SS316L material, the sample is first prepared by polishing and etching. Polishing removes any scratches or marks on the surface of the sample, while etching is done to reveal the microstructure. Etching is a chemical process that removes a thin layer of material from the surface of the sample, which highlights the different microstructural features.

After polishing and etching, the sample is placed on the microscope stage, and the objective lens is adjusted to focus on the area of interest. The illumination system provides light to the sample, which allows for the microstructure to be viewed. The microstructure can be observed and analyzed for any changes due to intergranular corrosion or sensitization.The optical microscope is a valuable tool in materials science and engineering as it allows for the observation and analysis of the microstructure of materials. The information obtained from optical microscopy can provide insights into the properties and performance of materials, which is essential in developing and improving materials for various applications.

Overall, the experimental work we are referring to involves testing the intergranular corrosion resistance of a part model made from SS316L material using powder bed fusion, cutting it to size using WEDM, heat treating it through a sensitization process, subjecting it to the ASTM A262 test, and viewing it under an optical microscope to observe any changes in the microstructure.

7.5 SCANNING ELECTRON MICROSCOPY:

SEM stands for Scanning Electron Microscopy, which is a type of electron microscopy that produces high-resolution images of a material's surface by scanning it with a focused beam of electrons. In the context of SS316L material, SEM analysis can provide important information about the microstructure, morphology, and surface features of the material.

To perform SEM analysis of SS316L, a small sample of the material is typically prepared by cutting, grinding, and polishing it to a smooth and flat surface. The sample is then placed in a vacuum chamber, where it is bombarded with a beam of high-energy electrons. The electrons interact with the atoms in the sample, producing a range of signals that can be detected and used to create an image.

One of the most common signals used in SEM analysis is secondary electrons, which are emitted from the surface of the material when it is struck by the electron beam. These secondary electrons can be detected and used to create a high-resolution image of the material's surface topography. By adjusting the parameters of the electron beam, SEM can also produce images that reveal the material's crystal structure and other features, such as cracks, voids, and inclusions.

In the context of SS316L material, SEM analysis can be used to observe any changes in the microstructure due to intergranular corrosion or sensitization. For example, intergranular corrosion can cause changes in the surface topography, such as the formation of pits or cracks, which can be observed using SEM. Similarly, sensitization can lead to the formation of chromium carbide precipitates along grain boundaries, which can also be observed using SEM.

In addition to imaging, SEM analysis can also provide important quantitative information about the material, such as its chemical composition and elemental distribution. This can be done using energy-dispersive X-ray spectroscopy (EDS), which detects the characteristic X-rays emitted by elements in the material when they are struck by the electron beam. By analyzing the spectrum of X-rays, EDS can determine the elemental composition of the material and provide information about its chemical bonding and oxidation state.

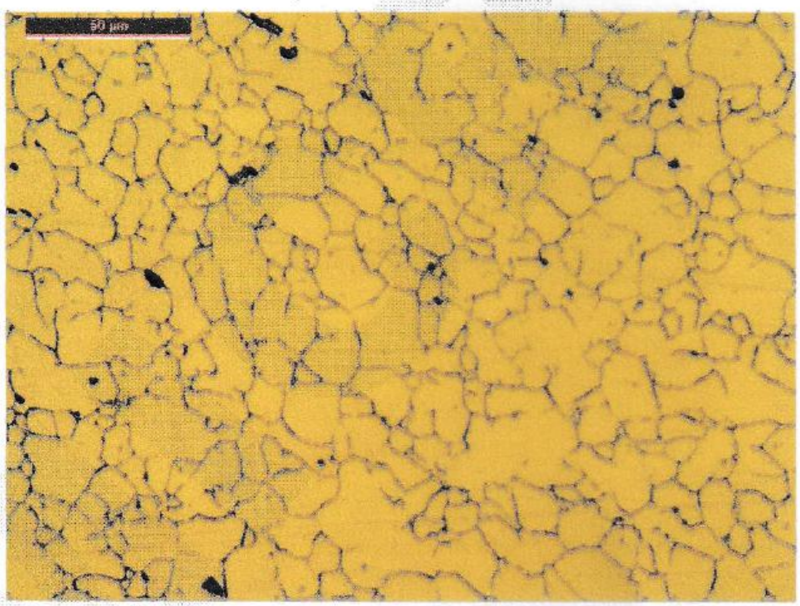
Overall, SEM analysis is a powerful tool for characterizing the microstructure and surface features of SS316L material, and can provide important information about its properties and behavior under different conditions.

7.6 ENERGY DISPERSIVE X-RAY SPECTROSCOPY (EDS):

Energy Dispersive X-ray Spectroscopy (EDS) is a technique used to analyze the elemental composition of a material. In the case of SS316L, EDS can be used to determine the presence and concentration of various elements such as iron, chromium, nickel, and molybdenum.During EDS analysis, a focused electron beam is directed onto the surface of the material. This beam causes the atoms in the material to emit X-rays with characteristic energies that correspond to the atomic elements present in the sample. These X-rays are then collected by a detector and analyzed to determine the elemental composition of the material.

In the case of SS316L, EDS can provide valuable information about the quality and composition of the material, particularly in areas of interest such as welds or areas affected by corrosion. By analyzing the elemental composition of these areas, it is possible to identify any changes or anomalies that may affect the performance or durability of the material.

COMMERCIAL SS316L –OM-IGC A262 PRACTICE A



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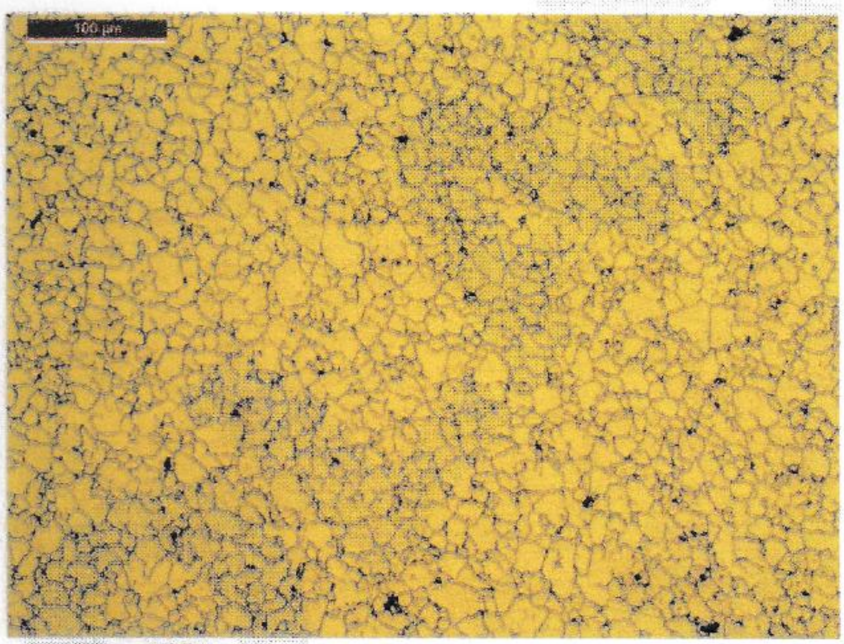

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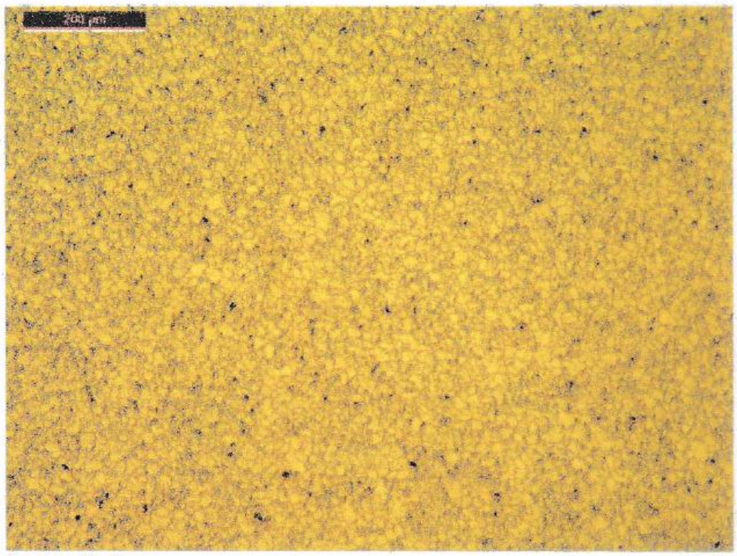
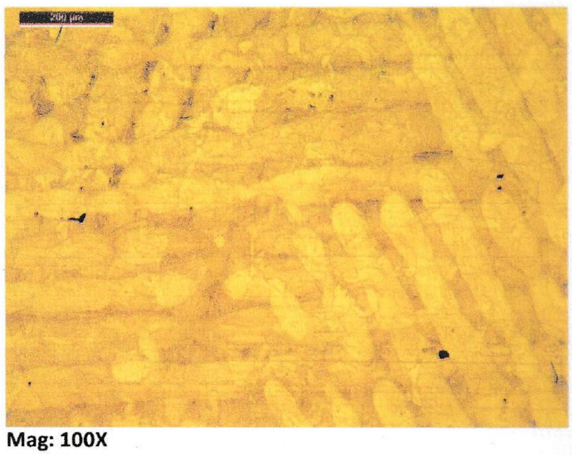
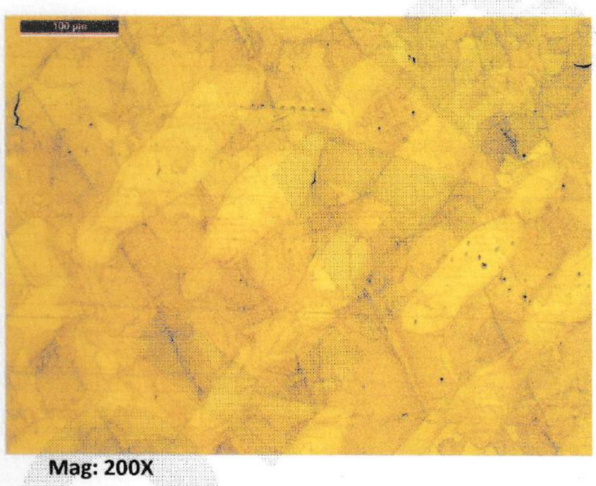


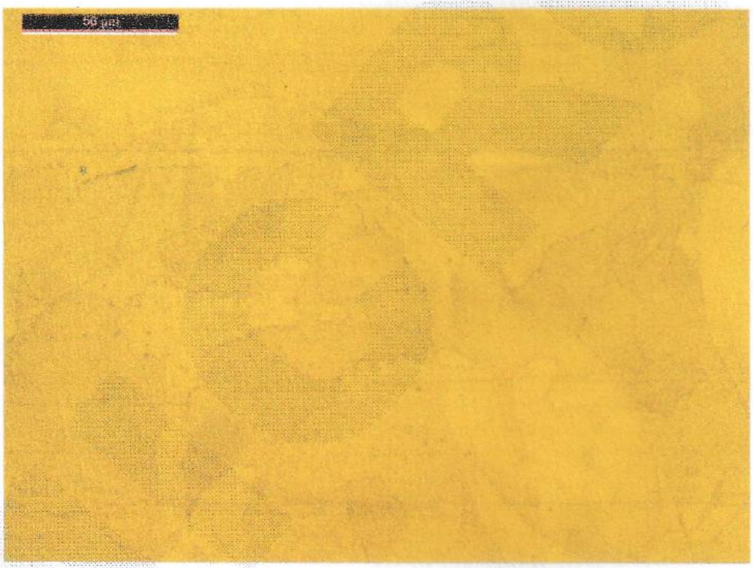
Mag: 100X

	Intergranular Corrosion Test (Practice - A)	**ASTM A262-2015 (RA-2021)**
	Test Conditions	**Value**
	Sensitization Temp (Degree celcius)	Specimen was sensitized at 675 °C for 1 hour
	Magnification	250x
	Etchant	10% Oxalic Acid Electro Etched
	Test Parameters	**Observation**
	Observation	Ditch Structure Observed at 250x magnification (Non Acceptable Structure as per ASTM-A262)
	Photos	The micro photograph is exhibited in Annexure – A

L-PBF SS316L –OM-IGC A262 PRACTICE A







Mag: 500X

	Intergranular Corrosion Test (Practice - A)	ASTM A262-2015 (RA-2021)
	Test Conditions	**Value**
	Sensitization Temp (Degree celcius)	Specimen was sensitized at 675 °C for 1 hour
	Magnification	250x
	Etchant	10% Oxalic Acid Electro Etched
	Test Parameters	**Observation**
	Observation	Non Identified Structure
	Photos	The micro photograph is exhibited in Annexure – A

CHAPTER 8

8.RESULT

8.1 STAINLESS STEEL

Stainless steel is widely used in various applications due to its excellent corrosion resistance properties. However, intergranular corrosion (IGC) is a major problem that affects the performance of stainless steel. In particular, austenitic stainless steel alloys, such as AISI 304L and AISI 316L, are prone to IGC due to their microstructure and chemical composition. In this study, the IGC resistance of AISI 304L and AISI 316L stainless steels was investigated in boiling nitric acid solution.Experimental Procedure: The specimens used in this study were solution annealed AISI 304L and AISI 316L stainless steels. The IGC resistance of the specimens was evaluated using the Huey test and the Strauss test. In the Huey test, the specimens were immersed in boiling 65% nitric acid solution for 48 hours. In the Strauss test, the specimens were immersed in boiling 50% nitric acid solution for 24 hours. The specimens were then examined for the presence of IGC using optical microscopy and scanning electron microscopy (SEM).: The results of the Huey and Strauss tests showed that both AISI 304L and AISI 316L stainless steels were susceptible to IGC in boiling nitric acid solution. Optical microscopy and SEM analysis revealed the presence of intergranular corrosion attack in both alloys. However, the extent of corrosion was higher in AISI 304L than in AISI 316L. This was attributed to the higher carbon content and lower nickel content in AISI 304L, which promotes the formation of chromium carbides and reduces the amount of available chromium for passivation.To further investigate the IGC behavior of the alloys, potentiodynamic polarization tests were performed in 1M

H_2SO_4 solution. The results showed that both alloys had similar passive behavior, indicating that the difference in IGC behavior was not related to the passive film formation. X-ray photoelectron spectroscopy (XPS) analysis revealed that the oxide film formed on the surface of both alloys was mainly composed of Cr_2O_3, Fe_2O_3, and Fe_3O_4. The amount of Cr_2O_3 was higher in AISI 316L than in AISI 304L, which may contribute to the better IGC resistance of AISI 316L.The IGC resistance of AISI 304L and AISI 316L stainless steels was investigated in boiling nitric acid solution. The results showed that both alloys were susceptible to IGC, but the extent of corrosion was higher in AISI 304L than in AISI 316L. This was attributed to the higher carbon content and lower nickel content in AISI 304L, which promotes the formation of chromium carbides and reduces the amount of available chromium for passivation. The potentiodynamic polarization tests showed that the passive behavior of both alloys was similar, indicating that the difference in IGC behavior was not related to the passive film formation. XPS analysis revealed that the amount of Cr_2O_3 was higher in AISI 316L than in AISI 304L, which may contribute to the better IGC resistance of AISI 316L. These findings are useful for selecting appropriate stainless steel alloys for applications where they are exposed to boiling nitric acid environments.

8.2 POWDER BED FUSION

Powder bed fusion (PBF) is a powerful manufacturing technique that can produce parts with high complexity, accuracy, and functional properties. The PBF process consists of several steps that take place in a controlled environment. The process starts with the preparation of the powder, followed by the preparation of the bed, layering, part building, and post-processing operations.SS316L is an austenitic stainless steel that is widely used in various applications due to its excellent corrosion resistance, high-temperature strength, and good weldability. PBF is an ideal method for producing complex geometries and precise parts from SS316L.The PBF process is highly precise and can produce parts with complex geometries that would be difficult or impossible to produce using conventional manufacturing techniques. The PBF process can also produce parts with internal features, such as channels or hollow sections.The final step in the PBF process is post-processing operations, which include removing the part from the bed, removing the excess powder, and cleaning the part. The cleaning process is critical in ensuring that the part is free from contaminants that could affect its properties.Heat treatment is also an essential post-processing operation that is used to improve the mechanical properties of the part. Heat treatment involves heating the part to a specific temperature and holding it at that temperature for a specified period.Overall, the PBF process is an effective manufacturing technique that is used across various industries to produce parts with high complexity, accuracy, and functional properties. The use of PBF for producing a compound in SS316L can lead to significant advancements in the field of material science and manufacturing.

The use of nitrogen-containing austenitic stainless steels could lead to more durable and reliable equipment and structures.The distribution of precipitates, specifically the presence of fine and uniformly distributed precipitates, had a positive effect on IGC resistance.The distribution of precipitates, specifically the presence of large and discontinuous precipitates, had a negative effect on IGC resistance.The annealing process could eliminate the dislocations and twins induced by cold rolling, leading to an improvement in the material's corrosion resistance.Observed that increasing the temperature and duration of exposure to the ferric sulfate solution resulted in a higher degree of IGC for both materials.The authors further analyzed the microstructural features of the steels to gain insight into the mechanisms underlying IGC. The results of the study indicate that aging treatment can have a significant effect on the intergranular corrosion resistance of AISI 304 stainless steel. SEM analysis of the samples revealed that aging treatment resulted in the formation of chromium carbide precipitates along the grain boundaries. The study demonstrates that aging treatment can be used to improve the intergranular corrosion resistance of AISI 304 austenitic stainless steel. The results of the study suggest that aging treatment at 550°C for 1 hour can provide the best intergranular corrosion resistance for this material. The study also showed that the welding parameters significantly affected the microstructure, hardness, and tensile properties of the welds.That the corrosion rate of SS316L increased with increasing chloride concentration in the solution.Annealing resulted in a significant increase in ductility and a decrease in hardness, while solutionizing followed by aging resulted in an increase in strength and hardness.The result showed that the SLM-produced SS316L exhibited excellent fatigue performance. the TIG welding process produced the best quality welds with the least amount of distortion and the highest joint efficiency. The study also showed that the welding parameters significantly affected the microstructure, hardness, and tensile properties of the welds

CHAPTER 9

9.CONCLUSION:

Stainless steel is widely used due to its excellent corrosion resistance, but intergranular corrosion (IGC) can affect its performance. AISI 304L and AISI 316L stainless steels are susceptible to IGC in boiling nitric acid solution, but the extent of corrosion is higher in AISI 304L due to its higher carbon content and lower nickel content. Powder bed fusion (PBF) is an effective manufacturing technique that can produce parts with high complexity, accuracy, and functional properties using SS316L. The use of nitrogen-containing austenitic stainless steels can lead to more durable and reliable equipment and structures. The distribution of precipitates, annealing process, and aging treatment can all affect the material's corrosion resistance. Increasing the temperature and duration of exposure to the ferric sulfate solution can also increase the degree of IGC for both materials. Based on the findings of the study, the use of nitrogen-containing austenitic stainless steels can lead to more durable and reliable equipment and structures. The distribution of precipitates and the annealing process can have a significant effect on the material's corrosion resistance. Increasing the temperature and duration of exposure to the ferric sulfate solution can result in a higher degree of intergranular corrosion. The aging treatment can improve the intergranular corrosion resistance of AISI 304 austenitic stainless steel by forming chromium carbide precipitates along the grain boundaries. The welding parameters significantly affected the microstructure, hardness, and tensile properties of the welds. Overall, these findings provide important insights into the properties and performance of austenitic stainless steels and can inform the development of more robust and reliable equipment and structures.

CHAPTER 10

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