

Experimental Trials on Laser Beam for Metal Cutting & Joining Operations

Submitted in fulfillment of the requirements for the award of
Bachelor of Engineering degree in Mechatronics

by

Anirudh R.P (39090001)

Saran Sundar S (39090048)



**DEPARTMENT OF MECHATRONICS ENGINEERING
SCHOOL OF MECHANICAL ENGINEERING**

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

**Accredited with Grade "A" by NAAC | 12B Status by UGC | Approved by AICTE
JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI - 600 119**

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **Anirudh R.P (39090028)**, **Saran Sundar S(39090048)** who have done the project work entitled "**Experimental Trials on Laser Beam for Metal Cutting & Joining Operations**" under our supervision from June 2022 to May 2023.

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Submitted for Viva Voce examination held on **May 2023**

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DECLARATION

We, **Anirudh R.P (39090001)** and **Saran Sundar S (39090048)**, hereby declare that the Project Report entitled “**Experimental Trials on Laser Beam for Metal Cutting & Joining Operations**” done by us under the guidance of **Dr. J.R. Deepak, M.E., Ph.D.** is submitted in fulfillment of the requirements for the award of Bachelor of Engineering degree in Mechatronics.

1. Anirudh R.P

2. Saransundar

DATE: May 2023

PLACE: Chennai, Tamil Nadu

SIGNATURE OF THE CANDIDATE

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ABSTRACT

Laser is versatile, it can be performed efficiently on a large range of materials, High precision, speed, and quality of laser machining are a few advantages of this technology. The compatibility of this technology makes it extremely convenient to incorporate into industrial lines. Laser can be focused up to 1/1000 of a millimeter. This review paper compiles the impact of various laser sources, industrial applications of laser on industries over conventional methods. It also summarizes the Laser Welding being used in the industries for précised manufacturing. The involvement of Laser in industrial activities has been a paradigm-shifting technological advancement in the field of engineering. Lasers are used in Industries for applications like cutting metals and fabrics, cleaning metallic surfaces, altering the surface roughness, measuring dimensions, and also to weld metals with high precision. Laser welding is predominantly used in automobile and aeronautical industries which would require engineering works to be carried out with high precision. Corten steel is high strength, high corrosion resistant, low maintenance, and cost-effective steel due to the presence of Ni, Cr elements alloyed to it. Corten Steel, when exposed to environment immediately forms a stable oxide (patina) layer which reduces corrosion, and hence it is commonly used in outdoor environments and other applications where other low-carbon steels would be inclined to corrosion. Laser Beam Welding (LBW) is extensively utilized in construction, railways and aerospace applications to join metals and alloys. In this research work, Corten A588 grade steel Laser Joints is prepared using a 3KW CO₂ Laser welding machine. Bead on Plate studies is carried out in 1.6 mm and 3 mm thick plate followed by which the Mechanical properties like hardness, tensile, bending and impact test is carried out and the microstructure of the LBW weld joints is investigated. The comparative advantages of choosing Laser Beam Welding over other welding process like Improved mechanical properties, microstructural properties, controlled heating, Narrow Heat Affected Zone (HAZ) and appealing weld bead formation makes it a better choice.

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LIST OF ABBREVIATIONS

SEM	Scanning Electron Microscopy
EDAX	Energy-dispersive X-Ray Spectroscopy
XRD	X-Ray Diffraction Analysis
Nd-YAG	Neodymium- Yttrium Aluminum Garnet
LMP	Laser Material Processing
ASTM	American Society of Testing & Materials
HSLA	High-Strength Low-Alloy
HAZ	Heat Affected Zone
FGHAZ	Fine Grain Heat Affected Zone
CGHAZ	Coarse Grain Heat Affected Zone
BM	Base Metal
BOP	Bead on Plate
LBW	Laser Beam Welding

CHAPTER 1

INTRODUCTION

The use of lasers in industry is a technological advancement that represents a paradigm shift in the field. Lasers are used in industry for applications such as cutting metals and fabrics, cleaning metal surfaces, changing surface roughness, measuring dimensions, and also for welding metals with high precision. Laser welding is mainly used in the automotive and aerospace industries, where technical work must be performed with high precision.

Today, lasers are used for high volume laser welding, laser marking of components, and additive manufacturing with lasers. Lasers are also used for finishing expensive metal parts that are subject to visible wear. It also plays a critical role in the emerging field of MEMS (micro-electro-mechanical systems) and nanotechnology. Lasers are also used in drilling; laser drilling achieves a full through hole by vaporizing the target material in tiny layers. The basic laser materials processing (LMP) system consists of a high-power laser, a beam delivery unit with a focusing arm, and a unit for monitoring beam parameters connected to a CNC machine. The transmission and manipulation of laser beams into extremely complex shapes and inaccessible locations is a critical aspect of the LMP system. The type of transmission is determined by wavelength, energy, power, beam diameter, divergence, etc.

Lasers are an energy source with extraordinary properties. Because of their unique properties, lasers have found applications in almost every field of human activity, be it science, medicine, industry, agriculture, entertainment or computer science. The reader can note that not all the basic properties of lasers are required for use in every application. In fact, it is the program that decides what all the features of the laser are for the successful implementation of the job. For example, high laser coherence is a key requirement in holographic applications, and plays a nominal role anyway, in distance sensing or, in this case, laser light. In this chapter, the industrial application of lasers is discussed briefly. Other applications are discussed in other sections.

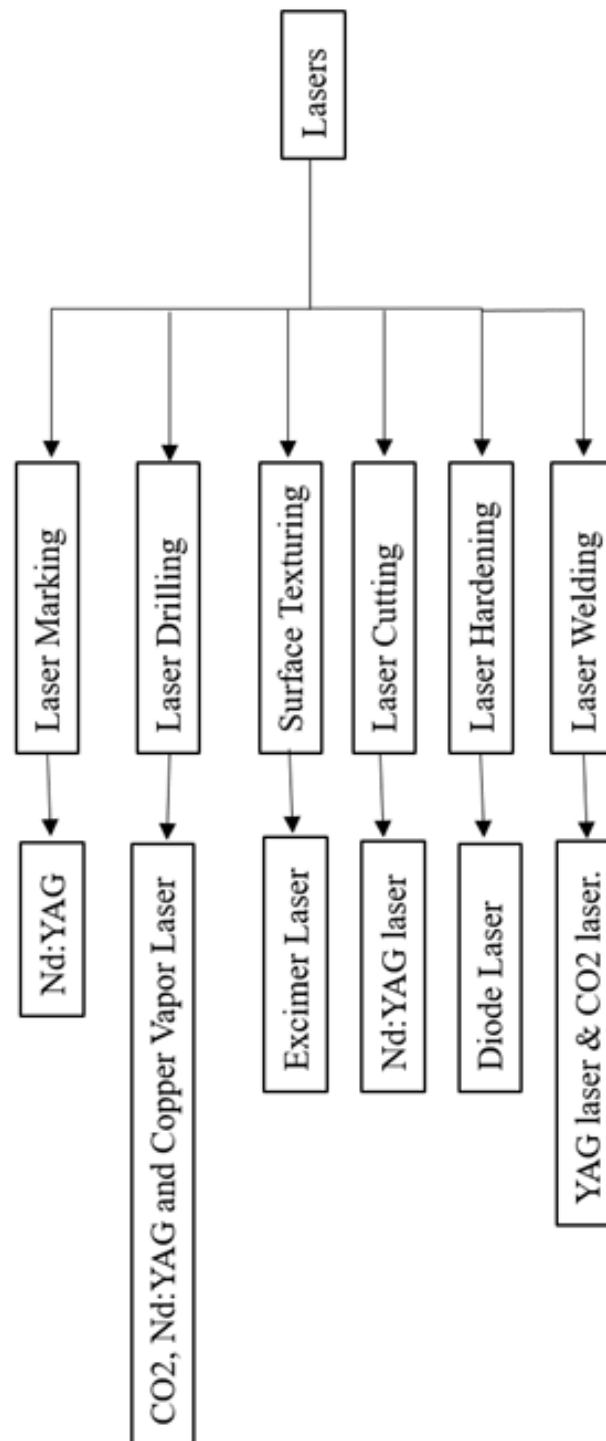


Fig:1.1 : Application and Laser Source used in the Industries.

Today, lasers are perhaps the most versatile tools available for a variety of material processing applications such as welding, drilling, cutting, heat treatment (quenching, annealing, glazing, plating, etc.) and highly specialized applications such as aerospace. Debris removal, laser leveling, remote decontamination and decommissioning of nuclear equipment, laser ablation, oil and gas exploration, automotive industry, etc. Hardened metals, composites and ceramics, compared to traditional mechanical material processing techniques. This section is intended to provide basic concepts rather than detail.

Both pulsed and CW lasers are used for industrial applications. Nd: YAG (~10KW), CO₂ (~25KW) and COIL (~40KW) are some of the most widely used high power lasers. The monochromaticity and high directivity of the laser cause low color dispersion and low divergence of the laser beam. Therefore, lasers can be focused on a very small spot, resulting in very high brightness.

1.1 LASER MATERIAL PROCESS

A basic laser material processing (LMP) system consists of a powerful laser, a beam delivery unit with a focus arm, and a beam tracking unit connected to a CNC machine. Aiming and manipulating laser beams in highly complex geometries and inaccessible locations is one of the key aspects of LMP systems. The transmission method is determined by wavelength, energy, power, beam diameter, divergence, etc. Near-infrared lasers such as Nd: YAG (1064 nm) and COIL (1315 nm) can be transported to the workplace using optical cables. You can bend it and adjust it according to your need. Bend the laser beam. 10.6 μ m CO₂ lasers must be delivered to the workspace using relatively cumbersome mechanical arms consisting of lenses, prisms, mirrors, etc., as there is no suitable optical cable to transmit the intense laser.

Material properties such as reflectivity, absorption, specific heat, thermal conductivity, heat capacity, diffusion, melting, latent heat of fusion and vaporization play an important role in LMP.

Since the material must absorb the laser energy, knowing how the laser interacts with the target material is critical in determining the type of laser to use in a particular material processing environment. The type of work, the speed of operation and the nature of the materials determine the type of laser used. In LMP, the material absorbs the laser energy, disperses it within the material, and removes it by vaporization or diffusion of the melt. During LMP, dirt, particles, smoke, etc. can damage the optics of the collection system. These can negatively affect the laser beam itself. A gas shield, primarily using helium, acts as a shield against them. Plasma and oxyacetylene cutting systems have their own gas nozzles. The LMP does not have this, so an auxiliary nozzle is provided by the compressed gas source. The plasma produced during laser processing reduces the laser's ability to penetrate. Plasma blowing is essential to improve system performance. When high-pressure gas enters the workpiece from above, a local pressure above atmospheric pressure is created under the workpiece. This pressure difference then helps to blow the melt from the floor. Modern LMP systems use coaxial nozzles with both laser and gas exiting the same orifice.

1.2 LASER BEAM WELDING IN INDUSTRIES

Laser welding is widely used in various industries such as automotive, shipbuilding, and bridge construction due to its advantages such as high productivity, automotive processing, and high-quality welding with small heat-affected zone. With laser welding, the strength of the connections is high, and the laser is focused on the required points, resulting in high accuracy. Laser welding is done by using laser radiation to bring the desired material or part to a molten state before the joining operation. Laser welding does not require electrodes or fillers, so materials are not susceptible to contamination or deformation. Laser welding is very precise and can create welds less than 1 mm. Laser welding results in a smaller heat affected zone.

Laser welding also exhibits faster processing times and is cost effective. It also has larger production capacities. Laser welding is therefore a newly emerging field where

production is carried out faster, with greater accuracy and precision. There are different types of lasers that are used in industry to perform different functions and operations. Laser sources like Ruby laser, CO₂ laser, Nd-YAG laser etc. are few laser sources which are generally used in industry. Both pulsed and CW lasers are used for industrial applications. Nd: YAG (~10KW), CO₂ (~25KW) and COIL (~40KW) are some of the most commonly used high power lasers. The high monochromaticity and directivity of the laser gives the laser beam a small dispersion of wavelengths and low divergence. Therefore, the laser can be focused to a very small spot size, resulting in very high luminance.

Cor-ten steel, also known as Weathering Steel, is a type of steel alloy that is designed to form when exposed to outdoor elements such as rain, snow and humidity. This layer of rust, or patina, protects the steel from further corrosion and gives it a unique aesthetic appearance. One of the main advantages of Cor-ten steel is its durability and resistance to corrosion. It is durable and can withstand harsh outdoor conditions, making it a popular choice for outdoor sculptures, architecture and landscaping. In addition, Cor-ten steel requires little maintenance and can be allowed to age naturally over time, making it a cost-effective and low-maintenance building material. Cor-ten steel is also a sustainable building material because it is made from recycled materials and can be recycled at the end of its useful life. It has a low carbon footprint and can be used in a variety of construction applications, including bridges, buildings and retaining walls.

1.3 LASERS CLASSIFIED ON THE BASIS OF FACTORS:

Different types of lasers are used in the industries depending on certain factors that they exhibit, the three well known properties of lasers include.

1.3.1 Monochromatic

A monochromatic laser is usually when the color of the laser beam has a specific color. The color of light is determined by the wavelength of the electromagnetic waves that make it up. This radiation is classified in the visible, infrared or ultraviolet spectrum.

1.3.2 Single Directional

A single directional laser beam has a fixed direction, a small beam diameter, and is nearly constant over long distances. This concentration of light allows the laser to achieve very high power. This level of concentration produces a megawatt high-energy pulsed laser that is strong enough to cut metal.

1.3.3 Coherent

Lasers are said to be coherent. That is, all the beams of the beam are synchronized and have the same polarity and phase. Coherence allows the beam to reach higher powers.

1.4 COMPONENTS OF A LASER SOURCE:

There are three important things that are required to have a working laser- Gain Medium, Energy Source and Two Mirrors.

1.4.1. Gain Medium:

Gain medium is the material you put in the laser cavity, it can be a solid or a liquid or a gas. The important feature of a gain medium is that it emits light in the desired wavelength when excited.

1.4.2. Energy Source:

The energy source is what causes the gain medium to emit light in the laser cavity. Very often, the energy source is a set of diode lasers which transforms electricity into light.

1.4.3 Mirrors:

The mirrors are put on both sides of the laser cavity with critical parallel alignment. The mirrors will bounce the light endlessly creating perfectly perpendicular light rays. The accumulation of light along the axis of the laser cavity eventually creates a high-power laser beam. This solves the first problem of creating a coherent laser beam out of randomly emitted light.

1.5 TYPES OF LASERS USED IN THE INDUSTRIES & APPLICATIONS:

Various types of lasers, its Applications used in the industry for different industrial operations are presented in the tabular column below.

Table 1.1 Types of Lasers and its applications in the Industry.

Type of Lasers	Wavelength	Applications
Nd:YAG(Nd-Yttrium Aluminium Garnet)	1064 nm 532 nm in second harmonic 355 nm in third harmonic	Marking applications and micro processing.
Nd:YVO4(Yttrium Vanadate)	1064 nm	Used in applications that require high peak and stable beam power.

Yb: Fiber (Ytterbium)	1090 nm	High average power and excellent cooling efficiency make it useful for marking operations on metals and plastics.
CO ₂	10.6µm	Used for marking, etching, and cutting operations.
He-Ne	630 nm	Measuring operations
Excimer	193 nm	Used in Lithography and surface texturing, also for optometry.
Argon	488-514 nm	Used primarily in biomedical-related research.
Copper Vapor Laser	510.6 - 578.2 nm	Commonly used for machining and laser cutting operations.
Diode Laser	810-1064 nm	Laser Hardening operations

Table 1.2 Types of Laser Machining operations performed in the industry and laser source involved.

Applications	Operation involved	Laser Source used for the application
Laser Marking	Used to imprint Unique Identification numbers of machine parts and products.	An Nd-YAG laser is generally used for marking operations. They emit invisible near IR beams with a wavelength of 1064 nm.
Surface Texturing	Formation of patterned microstructure on the surfaces of components to prevent friction-based wear and tear.	Excimer laser, a prominent UV laser used for its micrometer precision is generally used for lithography and surface texturing.
Laser Drilling	Its generally done by either melting or vaporizing the target material through the absorption of energy from a concentrated laser beam.	CO ₂ , Nd-YAG, and Copper Vapor Laser are generally used.

Laser Cutting	Employs a focused high-power beam to remove materials rapidly and produce very fine cuts.	Nd-YAG laser and is primarily used for laser cutting operations.
Laser Hardening	It employs a high-powered diode that applies energy to heat the localized area of the component's surface.	Diode Lasers are used for this process.
Laser Welding	It works by using laser radiation in order to melt the target material or workpiece down to a molten state and then joined.	For solid state welding YAG laser is used, and for gas- CO2 laser is used.

1.5.1. Laser Marking

Laser Marking is increasingly used in industries to imprint unique identification (UID) numbers of machine parts and products. Laser markings are highly durable and also withstand various cycles of sterilization in industries. Laser engraving can be applied on surfaces that are flat or curved.

1.5.2. Surface Texturing

Lasers are beneficial in creating patterned or textured microstructures on the surface of the components or products that would directly affect their physical performance. It would enhance the surface and is considered a viable and efficient way to modify the interaction between the surface for better lubrication and controlled friction.

1.5.3. Laser Drilling

Laser drilling is generally done by either melting or vaporizing the target material or the workpiece material through the absorption of energy from a concentrated laser beam. Usually, the melting process is considered more favorable because the energy required for melting is just 25% of that required for vaporizing.

1.5.4. Laser Cutting

Laser cutting employs a focused high-power beam to remove materials rapidly and produce very fine cuts. Lasers are capable of slicing through dense materials with relative ease, especially in materials like Titanium and Steel. Laser cutting is better than conventional cutting processes because of the speed at which the process is carried out, and the micrometer level precision as well as repeatability.

1.5.5. Laser Hardening

Laser Hardening is a heat treatment process that is used to improve the durability and strength of component surfaces. It employs the use of high-powered diode lasers that apply energy to heat the localized area of the component's surface. Laser hardening offers a lower risk of warping and cracking and also the advantage of greater precision and accuracy with broader material flexibility.

1.5.6. Laser Welding

Laser welding has been widely used in various industries in areas such as car manufacturing, shipbuilding, and bridge construction due to its advantages in the implementation of high production, automotive processing, and creating a high-quality weld with little heat impact zones. Laser-based welding provides more strength in the joints, and also the laser is concentrated at the necessary point, hence high precision. Laser welding works by using laser radiation in order to melt the target material or workpiece down to a molten state and then the joining operation is done. There are no electrodes or fillers necessary for laser welding operation, therefore the material is not prone to contamination and deformation. Laser welding is so precise that it can form welds smaller than a millimeter. In laser welding, the heat affected zone is smaller and

the total heat applied is much lower than traditional welding operations. Laser welding, also exhibits faster processing time, and is cost effective. It has greater production capacities too. Hence Laser Welding, is an emerging field where-in the production is done faster, with more accuracy and precision.

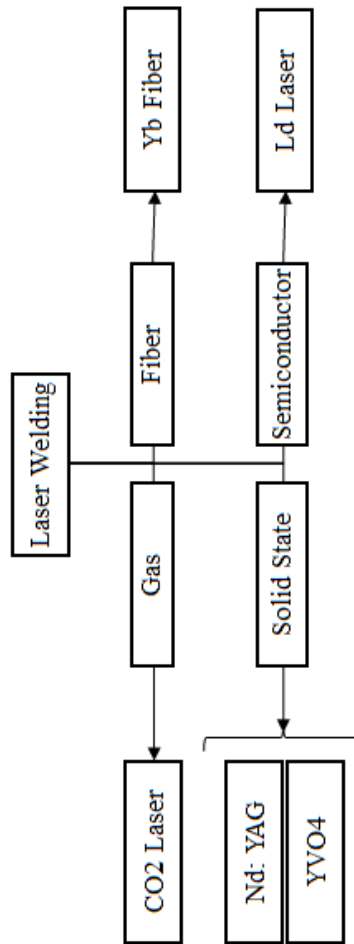


Fig: 1.2 : Types of Laser Welding Sources

1.6 ADVANTAGES & DISADVANTAGES OF LASERS IN INDUSTRIES

1.6.1. Advantages of Laser in Industries

- Lasers are extremely accurate; an advanced laser beam can be focused down to 1/1000 of a millimeter.
- The laser-based operations can be done with micro precision. Since laser possesses these advantages, it's widely used in Micromachining, Micro production & Nanotechnology.
- Machining using lasers is clean and free from post-machining burrs, making the entire process convenient. Lasers can easily be incorporated into production lines in order to achieve a more standardized operation.
- Manufacturing using lasers results in shorter cycle times, lower maintenance, and relatively cost-effective production.
- Laser is versatile, it can be performed efficiently on a large range of materials like fabric, glass, and metal. It's also used in the healthcare industry because of its micron-level accuracy.
- Lasers have a reduced effect on the environment, making them more energy efficient. Implementing laser technology would reduce carbon emissions.
- Lasers are compact, hence more economical production lines. Automated Laser machines create safer manufacturing floors eliminating risky manual processes.

1.6.2. Disadvantages of Laser in Industries

- In order to perform certain laser operations, the operator must require a certain amount of expertise. An experienced operator should be well versed and equipped with knowledge of different material compositions in order to perform the operations in a very efficient manner. Hence acquiring proper manpower for carrying out a laser-based manufacturing operation is a task.
- The materials upon which the laser is used tend to get evaporated quickly. Eg: Upon cutting plastics, evaporation tends to occur. If the device is set up

incorrectly, and if the operator is unaware of the material properties, then it would cause significant damage.

- Another added disadvantage is the limitations to the metal thickness. Laser operations like laser cutting can be used on a wide range of metals but the thickness of the metal would be in the range of 15mm to 20mm.
- To procure a laser machine, the initial investment is significantly high.
When it comes to laser welding, the common defects include Gas Entrapment, Porosity and Cold Bonding.

The graphical representation of common Laser Welding Defects are shown below.

1.6.2.1. Solidification Cracking/Centre-line Cracking

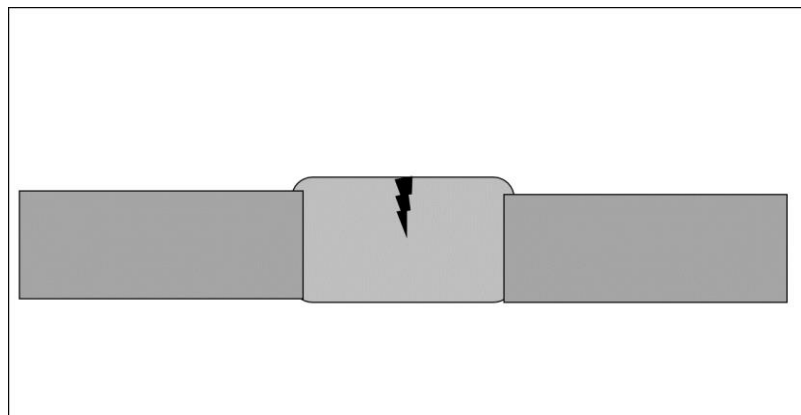


Fig:1.3 : Solidification Cracking/Centerline Cracking

The main cause of solidification cracking is the geometry of the weld profile. The high depth-to-width ratio of laser welds leads to buckling, which means high thermal stresses across the weld where the solidification fronts intersect, leading to centerline cracking. Increase local tension. Therefore, laser welding requires precise control of the welding geometry.

Full penetration laser welding is less prone to solidification cracking than partial penetration laser welding. The potential for solidification cracking in laser welding can limit the possible welding speed, base material composition, or weld penetration depth when laser welding steel and aluminum.

1.6.2.2. Porosity

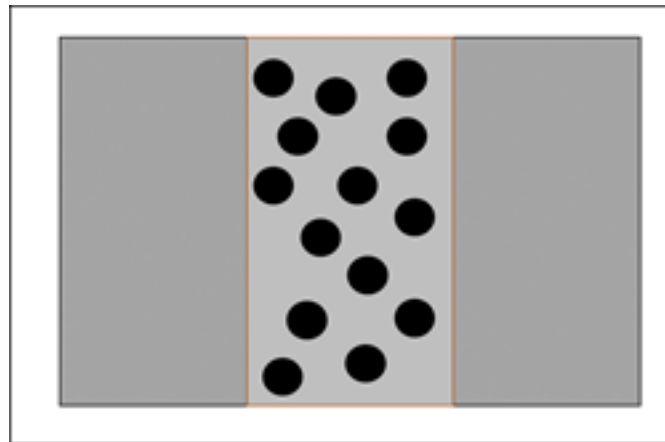


Fig: 1.4 : Porosity Defect on the weld bead

Porosity is less defect in laser welding than solidification crack. Porosity in laser welding can be caused by plate or surface contamination or improper pre-cleaning. However, in laser welding, porosity can also be caused by instability or collapse of the laser keyhole during partial penetration high-power laser welding.

Laser welding is protected by inert gas shielding. If this shielding is insufficient (due to too much or too little gas flow), porosity may occur. Porosity can be a particular problem in aluminum laser welding due to hydrogen evolution in the weld metal. Hydrogen can come from moisture in the air, surface oxides, or improper preclearing.

1.7. LASER WELDING

Laser welding is a process used to join metals or thermoplastics using a laser beam to form a weld. This concentrated heat source allows laser welding with high welding speed of meters per minute on thin materials and narrow and deep welds between square pieces on thick materials.

Laser welding is now prevalent in the field of Automobile and Aeronautical field, the primary advantage of laser welding over primitive welding methods is as follows:

- Increased Production rates
- Reducing Production Cost
- Accuracy
- Repeatability
- High Quality weld (with micron level precision)
- Laser Welding has high power density on the order of 1 MW/cm^2 resulting in small heat affected zones, the weld spot size can vary between 0.2-13mm.
- Its capable of welding wide variety of materials notably – Carbon steels, HSLA steels, aluminum, titanium, stainless steel.



Fig: 1.5 : Laser Welding of Corten Steel

1.7.1 Laser Welding Vs Conventional Methods

Compared to the conventional welding methods, the laser welding is more advantageous because-

- In laser welding, the heat affected zone is smaller and the total heat applied is much lower than traditional welding operations.
- Laser welding, also exhibits faster processing time, and is cost effective. It has greater production capacities too.
- Laser welding is suitable to join thin and delicate metal parts to great precision, it also prevents distortions and internal stresses.

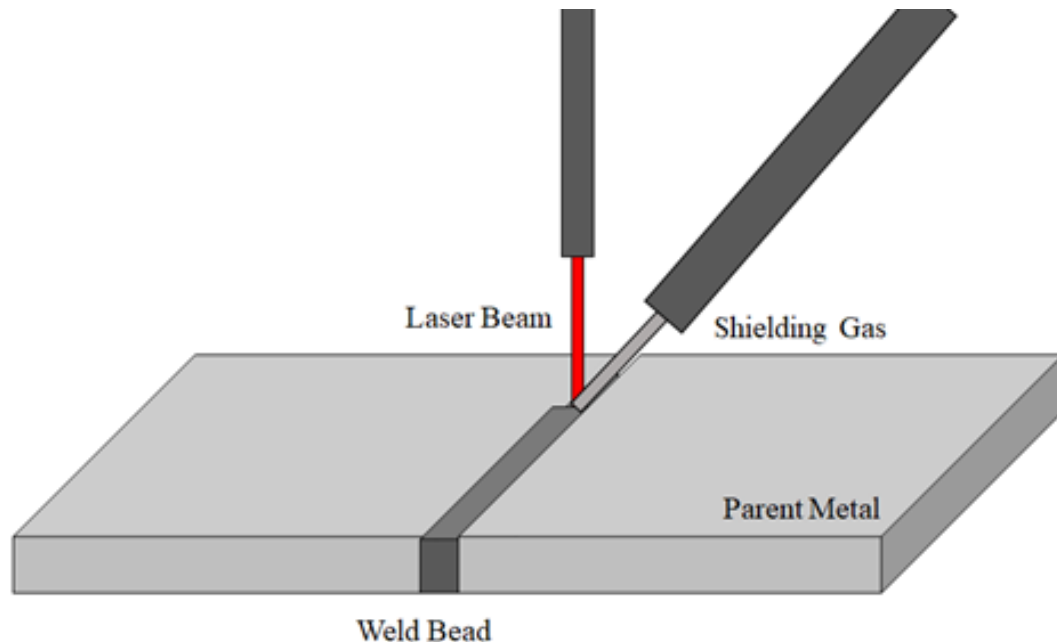


Fig: 1.6 : Schematic diagram of laser welding on 2 metals

1.7.2 Application of Laser Welding in Industries

Automotive and Railway Industry: Laser welding is commonly used in the automotive industry for welding body parts, exhaust systems, fuel tanks, and engine components. It is also used for repairing engine blocks, cylinder heads, and transmission parts. It's also called Railway Steel for this reason of application.

Aerospace Industry: Laser welding is used in the aerospace industry for welding aircraft engine parts, turbine blades, and rocket engine components. It is also used for repairing and maintaining aircraft parts.

Electronics Industry: Laser welding is used in the electronics industry for welding components in electronic devices, such as smartphones, laptops, and other consumer electronics.

Medical Industry: Laser welding is used in the medical industry for welding medical devices, such as surgical instruments, dental implants, and prosthetics.

Jewelry Industry: Laser welding is used in the jewelry industry for welding precious metals, such as gold, silver, and platinum.

Manufacturing Industry: Laser welding is used in the manufacturing industry for welding metal parts, such as gears, pipes, and tubes. It is also used for welding plastics and ceramics.

1.8. MATERIALS AND PROCESS:

1.8.1. Corten A588 Grade Steel

Weathering steel is often referred to by the generic name COR-TEN steel and is sometimes written as corten steel without the hyphen. The ASTM International Standards Group has given the original COR-TEN the standard name A242 (COR-TEN A). A588 (COR-TEN B) and A606 are the latest ASTM ratings for thin sheets. Alloys are produced and used in similar quantities. A layer of Rust/ Patina is formed on the surface of the Corten Steel when exposed outdoors. This layer of rust, or patina, protects the steel from further corrosion and gives it a unique aesthetic appearance. One of the main advantages of Cor-ten steel is its durability and resistance to corrosion.

It has a long lifespan and can withstand harsh outdoor conditions, making it a popular choice for outdoor sculptures, architecture, and landscaping features. Surface treatments can accelerate oxidation by up to 1 hour, but surface oxidation on weathered steel takes 6 months.

1.8.2. IRSM: M-41-97-RDSO:

- Tensile strength is at least 440 MPa and 480 MPa.
- Strength of yield: 340 MPa min, 300 MPa min
- EL Elongation 5.65 square root of SO 24 min. 26% min.
- The gauge length is EL.
- The cross-sectional area is SO.

The general material properties of the materials are as above mentioned.

1.8.3. Laser Welding using Fanuc Robot:

Laser welding of Corten steel using a robot arm is a viable option and has several advantages over other welding techniques. Corten steel is a type of weathering steel that is known for its durability and resistance to corrosion. Laser welding is a precise and efficient welding technique that uses a high-energy laser beam to melt and join two pieces of metal together.

When using a robot arm for laser welding, the process is automated, which can increase the accuracy and speed of the welding process. The robot arm can be programmed to move in a precise pattern, ensuring consistent and high-quality welds. Additionally, the robot arm can reach difficult or tight spaces, making it an ideal choice for welding complex geometries.



Fig: 1.7 : Fanuc Robots used for Laser Welding

1.8.4. Micro Structure analysis:

The microstructural analysis is used widely in industry to evaluate products and materials. Performance, response to the environment, and failure mechanisms are just some of the areas in which microstructural analysis can be utilized to assess and develop products. The basic assessment of particular characteristics, such as grain size or coating thickness, through porosity and pore structure, to complete characterization of multi-component systems or evaluation of deterioration or failure causes are all examples of microstructural evaluation. Specimens were properly prepared in order to ensure accurate microstructure observation and interpretation. The four transverse cross-sections that had been received were first ground and re-polished before being mounted in a clear medium of the acrylic variety in accordance with the accepted procedures of the most recent revision of ASTM E3. With magnifications up to 500X, the completed cross-sections were inspected in the etched environment using a metallurgical microscope.

1.8.5. Tensile Test:

Tensile test is a method of destructive testing method that provides knowledge about the Tensile and yield strength, the ductility of the material. It is also significant in measuring the force that's required to break a composite or plastic specimen and the extent to which the specimen stretches or elongates to that breaking point.

Mechanical Testing/Tensile Testing is carried out to generate data to understand better about the material joining procedure. The data provided is essential that the limiting values that a structure can withstand without failure are known.

The tensile breaking test is a common method used to determine the mechanical properties of materials, particularly metals and plastics. It is used to measure the tensile strength, yield strength, and elongation of a material. During the test, a sample of the material is pulled apart by two grips at a constant rate of deformation. The force required to break the sample is measured using a load cell, and the deformation is measured using an extensometer. The load and deformation data are used to create a stress-strain curve, which shows how the material behaves under tension.

1.8.6 Vickers Hardness Test:

The Vickers hardness test is a commonly used method to measure the hardness of materials, particularly metals. It is based on the indentation hardness principle, where a small diamond indenter is pressed into the surface of the material with a known force, and the resulting indentation size is measured and used to calculate the material's hardness.

The Vickers hardness test is a microhardness test, meaning that it is typically used to measure the hardness of thin or small specimens or areas. The test is performed by applying a load of typically between 1 and 120 kgf for a period of 10 to 15 seconds.

For Hardness Testing, the procedure of Vickers Micro Hardness Test was conducted on the weld material, the materials had a thickness of 1.6mm and 3mm. The Vickers hardness test method, also known as the microhardness test method, is mainly used for working with small parts, thin parts or depth of hardening.

The Vickers method is based on an optical measurement system. The microhardness test method, ASTM E-384, specifies a range of light loads using a diamond indenter to create an indentation that is measured and converted into a hardness value. It is very useful for testing different types of materials, but the test sample must be very polished to measure the molding size.

Upon conducting Vickers Hardness Test, force is applied on the sample using an indenter attached to the machine, and the table is adjusted to the required height. The test force slowly increases to a certain value and after being held at a certain value for some time, the indenter returns to its original position and the dent created by the test force is studied. Significant benefits and applications of Vickers Hardness, tensile test are as follows

Material Selection: The tensile test is an important tool for selecting the right material for a particular application. By performing tensile tests on various materials, engineers can determine the strength, ductility, and other properties of the material and select the one that meets the requirements of their application.

Quality Control: Tensile testing is used in the manufacturing process to ensure that the materials used in a product meet the required specifications. Tensile testing can be used to detect defects, such as cracks, in the material that may compromise its strength.

Material Development: Tensile testing can be used to develop new materials with specific properties. By understanding the tensile properties of different materials, researchers can design and develop new materials with improved strength, ductility, and other properties.

Failure Analysis: When a material fails, Vickers hardness testing can be used to determine the cause of the failure. By analyzing the Vickers hardness properties of the material, engineers can determine whether the failure was due to a material defect, improper manufacturing, or other factors.

CHAPTER 2

LITERATURE SURVEY

The following literature survey has been done on the industrial applications of laser, predominantly the experimental works done in the field of Laser Welding.

X. Cao, M. Jahazi et al (2005) - A review of laser welding techniques for magnesium alloys: The material used to laser weld in this experimental setup is Mg Alloy, and the laser used CO₂ Lasers and Nd: YAG lasers. Mg Alloys and other dissimilar metals and composites would be welded in the future because of its low cost, high quality, repeatable. The easy manipulation and control of Nd: YAG lasers through optical fiber delivery provides welding opportunities for complex geometries where 3D welding may be carried out.

E. Akman, A. Demir et al (2009)-Laser welding of Ti₆Al₄V titanium alloy: The material used to laser weld in this experiment Ti₆Al₄V (Titanium Alloys) and Nd: YAG pulsed laser is used as the laser source. You could see that the peak performance is the most important parameter in determining a penetration depth equal to pulse-to-pulse energy duration. If the peak power is too high, the temperature of workpieces exceeds the evaporation point Ti₆Al₄V alloy, which supports the formation of craters on the surface materials.

G. Sierra, P. Peyre (2007) Steel to aluminium key-hole laser welding: Low carbon DC 04 steel and 6000 series Aluminium is welded using YAG lasers. Defect free welds were obtained on overlap Al-steel joints. Welds obtained in Aluminium-on-steel configuration always exhibit cracks on the weld-steel interfaces.

X. Cao, W. Wallace et al (2003)-Research and Progress in Laser Welding of Wrought Aluminum Alloys. I. Laser Welding Processes: 5000 and 6000 series alloys are welded using YAG alloys. Defect free welds were obtained on overlap Al-steel joints. Welds

obtained in Aluminium-on-steel configuration always exhibit cracks on the weld-steel interfaces.

Shuhai Chen, Liqun Li et al (2011)-Joining mechanism of Ti/Al dissimilar alloys during laser welding-brazing process. A CO₂ Laser is used in this experimental setup. A fusion line with fine microstructure was formed by diffusion of element Si from weld pool to semi molten zone at solid/liquid interface.

V. Errico, S.L. Campanelli (2020) On the feasibility of AISI 304 stainless steel laser welding with metal powder. An Ar Laser on AISI 304 stainless steel plate with AISI 316 L powder as filler. The analysis of variance indicated that the laser power, translation speed, feed rate, laser spot diameter affected the depth of penetration and track width, but porosity is affected only by laser spot diameter and carrier gas flow rate.

Assist. Prof. Lisiecki Aleksander (2012) Laser Welding of Titanium Alloy Ti6Al4v Using a Disk Laser. The bead-on-plate weld beads were produced on the titanium alloy Ti6Al4V (Grade 5 according to ASTM B265) sheets 2.0 mm thick at different laser power and melting speed to simulate the butt joint welding without additional material.

Xiongfeng Zhou, Ji'an Duan et al (2019) The Study on Mechanical Strength of Titanium-Aluminum Dissimilar Butt Joints by Laser Welding-Brazing Process. Laser welding was performed in the butt configuration of Ti6Al4V and 5A06 plates with a thickness of 1.5 mm by focusing the laser beam on the 5A06 aluminum alloy side without filler metal. The effects of laser offset, welding speed and laser power on joint expansion length, IFZW, fracture roughness, IMC thickness and tensile strength were investigated.

J. M. Sánchez Amaya et al (2013) Laser welding of light metal alloys: Aluminium and titanium alloys. Nd: YAG, CO₂ Lasers are used for this experiment. The process parameters of Aluminium and Titanium alloys have been studied and tabulated in detail.

Anderson C. N. Clayton Nascimento Ribeiro et al (2021) Improvement weldability of dissimilar joints (Ti6Al4V/Al6013) for aerospace industry by Laser beam welding. The experiments carried out and the results obtained in this work aimed to investigate and optimize the weldability of the dissimilar joint AA6013 and Ti-6Al-4V obtained by the laser welding process.

K. Kalaiselvan, A. Elango et al (2014) Studies on Ti/Al Sheet Joint Using Laser Beam Welding – A Review Gaussian mode laser welding required high laser power and high welding speed, while donut mode required high laser power and low welding speed for efficient laser beam welding. The amount of residual stress generation in the donut mode was higher compared to the Gaussian mode of laser welding.

Peter O. Omoniyi, Rasheedat M. Mahamood et al (2021) Impact of Process Parameters of Laser Welding On the Mechanical Properties of Ti6Al4V. Higher welding speed, input energy and welding power are beneficial for reduced porosity, reduced under fill, high quality bead shape and optimum hardness.

Influence of Pulse Width in laser assisted texturing on moly-chrome films (2018)- V. Ezhilmaran, L. Vijayaraghavan et al. Two different lasers, namely nanosecond and femtosecond pulsed lasers, were used to form continuous microchannel on the surface of automobile piston rings. Tribological measurements were performed to compare the frictional properties of the samples made with laser pulse widths of nanoseconds and femtoseconds respectively.

A technical review of the laser drilling of aerospace materials (1994)- C.Y. Yeo, S.C. Tam et al. In this article, the physical mechanism of laser processing, types of lasers and different laser drilling processes are explained. The use of laser drilling in the aerospace industry is very promising in terms of its features and benefits. However, it is intended for applications that require tight tolerances and high accuracy.

Review of Laser Welding Monitoring (2014)- D.Y. You, X.D. Gao et al. From this review article, it can be concluded that non-contact optical sensing can be considered an ideal real-time monitoring technique for laser welding. Photodiode sensors have low cost, simple construction and provide a lot of information about high frequency characteristics. This makes it compatible with industrial production. The visual camera provides a lot of spatial information and detects welding defects on the weld surface with high accuracy.

The Role of CO₂ Laser and Fractional CO₂ Laser in dermatology (2014)- Tokuya Omi & Kayoko Numano. CO₂ laser is an efficient, precise and safe system for dermatologists. Technological advances in CO₂ laser structures have led to smaller spot sizes, increased precision in laser surgery, and greater tip size and protocol flexibility for fractional CO₂ laser treatment. It is expected that the range of applications of CO₂ lasers in the skin will continue to expand in the future.

A review of laser welding techniques for Magnesium Alloys (2006)- X. Cao, M. Jahazi et al Laser welding is likely to become an important joining technology for magnesium alloys that can facilitate a wide range of applications in the aerospace, aircraft, automotive, electronics and other industries. To date, it has been used to investigate the weldability of magnesium alloys. For years, two main types of industrial lasers have been used: CO₂ and Nd:YAG. For some magnesium alloys, especially forging materials, with suitable laser processing parameters, crack-free laser welded joints with low porosity and good surface quality can be obtained.

Laser Ablation of Polymers: A review (2019)- Sandeep Ravi-Kumar, Benjamin Lies et al A high repetition rate may not leave enough time for the plasma to disperse during vaporization, thus reducing the effectiveness of successive pulses due to interference. Higher molecular weight can result in lower ablation rates due to the formation of highly viscous molten material during ablation. A larger thermal conductivity of a material can lead to a larger heat-affected zone, specifically with longer pulse durations.

Laser surface texturing and related techniques for enhancing tribological performance of engineering materials: A review (2020)- Bo Mao, Arpith Siddaiah et al. This paper reviews the recent advances and developments of LST for enhanced tribological properties of engineering materials. The process designs of LST by means of direct laser ablation, laser interference, and laser shock processing are discussed. The effects of laser parameters on the texture features are highlighted. The enhanced tribological properties of LST-processed materials and their applications on various fields are reviewed. The current challenges and future directions of LST techniques are discussed.

Developments in laser welding of aluminum alloys (2021)- D. Wallerstein, A. Riveiro et al In order to obtain high-performance aluminum–steel joints, it is highly desirable to control as much as possible the formation of imperfections, and to maximize the wettability of aluminum on steel. However, there are no general rules that could lead us to the optimal processing conditions. Although they can be adjusted individually, there are important interactions between them, in such a way that usually the parameters have to be adjusted simultaneously: for example, in order to increase wire feeding, laser power has to be also increased to guarantee enough wire melting

Laser Welding Process – A Review of Keyhole Welding Modelling (2015)- Josephine Svenungsson, Isabelle Choquet et al. The variety of these models and some of the simplifications discussed in the previous sections show that this field is still under development. For instance, the influence of the temperature dependence of the material properties has been little investigated. The thermodynamic properties of the

most common solid metals used in welding are in many cases well known. However thermodynamic and transport properties of these metals in liquid phase are documented over a rather narrow range of (low) temperature that does not cover the complete liquid temperature range

J.R. Deepak et V.K. Bupesh Raja (2021)- Microstructure and metallurgical property investigation of welded IRSM 41-97 rail steel joints. The microstructure of IRSM 41-97 rail steel base metal consists of dual band of a ferrite grains and intergranular pearlite grains with a grain size 25–30 mm Equiaxial pearlite and ferrite grains distributed are perpendicular to the rolling direction which is due to the controlled rolling of IRSM 41-97 rail steel sheets during manufacturing process. The microstructure of AGTAW IRSM 41-97 rail steel at HAZ consist of uniform fine pearlite grains of size 15–20 mm. Coarse ferrite (CF), grain boundary ferrite (GBF), fine pearlite (FP), ferritelath (FL) are formed in the Heat Affected Zone (HAZ)

J.R.Deepak, J. Jeya Jeevahan et al (2021) - XRD investigation of GTAW, GMAW, LBW and AGTAW Corten A588 grade steel weldments The grain size of the LBW weldment is very small as 8 mm which leads to increase in the strength of the LBW weld Among welded Corten A588 steels and Corten A588 Grade steel BM, LBW welded Corten A588 Grade steel showed exceptional properties, making the LBW welding more suitable for CortenA588 Grade Steel where quality cannot be compromised.

Mikhail Sokolov, Antti Salminen et al- Laser welding and weld hardness analysis of thick section S355 structural steel Increase in the welding speed results in an increase in the average weld hardness and decrease in the average HAZ width. Increase in the laser power gives a decrease in the average weld hardness and increase in the average heat HAZ width. The hardness of the weld tends to reduce with increasing line energy for material of thickness 20 mm. For 25 mm thickness increase in the line energy does not show significant changes in the weld hardness; average weld hardness remains at the same level – 480 HV5. The difference between the base

material hardness and the weld hardness may be reduced by decreasing the welding speed or by the use of preheating techniques.

Yanli Song, Lin Hua et al- Characterization of the inhomogeneous constitutive properties of laser welding beams by the micro-Vickers hardness test and the rule of mixture In this work, three types of tailor (laser) welded blanks, fabricated from automotive DX56D and DP600 steel sheets, were considered. The relationship between the micro-Vickers hardness value and material parameters (i.e., the strain hardening exponent, the strength coefficient and Young's modulus) was quantitatively built

Bekir Sami Yilbas et Sohail Akhtar (2011)- Laser welding of Haynes 188 alloy sheet: thermal stress analysis Laser Welding of HAYNES 188 alloy steel was carried out. Temperature and Stress fields in the region are predicted using the ABAQUS numerical code. An experiment is carried out to examine the morphological and microstructural changes in the welding section. It is found that temperature in the welding section, in particular in the irradiated spot well, exceeds the melting temperature of the substrate material and superheating in the liquid phase takes place in the melt pool.

Bekir Sami Yilbas, Abul Fazal Arif et al (2010)- Laser welding of low carbon steel and thermal stress analysis Laser welding of mild steel sheets is carried out and stress field developed in the welding zone is modeled using the finite element method (FEM). The residual stress developed in the weld region is measured using the XRD technique and compared with the FEM predictions. The morphological and metallurgical changes in the welding region are examined using the optical microscopy and the SEM. Microhardness distribution across the welding zone is measured.

Table 2.1 : Summary of Review on Laser Applications

Sl.No.	Material Used	Laser Used	Inference
1	Mg Alloy	CO ₂ Lasers & Nd:YAG lasers	Mg Alloys and other dissimilar metals and composites would be welded in the future because of its low cost, high quality, repeatable. Easy handling and control of Nd: YAG lasers through fiber optic delivery provides welding capabilities for complex geometries where 3D welding can be performed.
2	(Titanium Alloys)	Lumonics JK760TR Nd:YAG pulsed laser	You could see that peak performance is the most important parameter in determining penetration depth equal to pulse-to-pulse energy duration. If the peak power is too high, the temperature of the workpieces will exceed the vaporization point of the Ti6Al4V alloy, which promotes the formation of craters on the surface materials.
3	Low Carbon DC 04 Steel to 6000 series Aluminium	YAG lasers	Flawless welds were obtained on overlapping Al-steel joints. Welds obtained in the aluminum-on steel configurational ways show cracks at the weld-steel interface.
4	5000 & 6000 series alloys	Nd:YAG lasers	The easy handling and control of Nd: YAG lasers using fiber optic feed provides welding options for complex geometries where overhead, vertical, horizontal or all position welding can be done effectively and efficiently.

			Process control and monitoring is required for such applications.
5	Ti-Al dissimilar metal welding.	CO ₂ Laser	A melt line with a fine microstructure was formed by diffusion of the Si element from the weld pool into the semi-molten zone at the solid/liquid interface.
6	AISI 304 stainless steel plate with AISI 316 L powder as filler.	Ar Laser	Variance analysis showed that laser power, translation speed, feed rate, laser spot diameter affected the penetration depth and track width, but porosity is only affected by laser spot diameter and carrier gas flow.
7	Laser Welding Of Titanium Alloy Ti6Al4v Using A Disk Laser	Disk Laser	The weld balls were made on Ti6Al4V titanium alloy (Grade 5 acc ASTM B265) 2.0 mm thick sheets at different laser power and melting speed to simulate butt welding without additional material.
8	The Study on Mechanical Strength of Titanium-Aluminum Dissimilar Butt Joints by Laser Welding-Brazing Process	-	Laser welding - butt brazing of Ti6Al4V and 5A06 sheets with a thickness of 1.5 mm the configuration was made by focusing the laser beam on the 5A06 aluminum alloy side without filler metal. The effects of laser offset, welding speed, and laser power on spread length, IFZW, fracture roughness, IMC thickness, and joint tensile strength were investigated.

9	Laser welding of light metal alloys: Aluminium and titanium alloys	Nd:YAG, CO ₂ , fibre laser, diode laser can be used	The process parameters of Aluminium and Titanium alloys have been studied and tabulated in detail.
10	Improvement weldability of dissimilar joints (Ti6Al4V/Al6013) for aerospace industry by Laser beam welding	Ytterbium fiber lasers	The experiments performed and the results obtained in this work were intended to investigate and optimize the weldability of a dissimilar joint of AA6013 and Ti-6Al-4V obtained by a laser welding process.
11	Review on Laser Welding of Titanium Alloy	Co ₂ Laser ,Nd: Yag Laser, Disk Laser, Diode Laser ,Fiber Laser	Gaussian mode laser welding required high laser power and high welding speed, while donut mode required high laser power and low welding speed for efficient laser beam welding. The residual stress development magnitudes were found to be higher in the donut mode compared to the Gaussian mode of laser welding.
12	Impact Of Process Parameters Of Laser Welding On The Mechanical Properties Of Ti6al4v A Review	CO ₂ Laser	Higher welding speed, energy input and welding performance, are beneficial for reduced porosity, reduced under fill, good bead geometry and optimal hardness

CHAPTER 3

AIM & SCOPE OF THE INVESTIGATION

3.1 AIM:

The main aim of the research work conducted is to benchmark the parameters for metal cutting and joining applications using a laser. The data inferred from the research work can be used as a parameter-deciding chart for industrial practices. Properties of weathering steel - Corten A588 Grade steel, IRSM 41-97.

3.2. SCOPE OF INVESTIGATION:

The project mainly focuses on Laser welding analysis for material joining and cutting. Laser welding has its very own advantages. For many manufacturers, investing in laser welding has proven to be a highly profitable move because it shortens cycle times and post-processing procedures while increasing productivity and return on investment (ROI). When compared to other robotic welding techniques like resistance welding or MIG welding, it can be incredibly useful in some applications. Depending on the requirements of your application, laser welding offers a variety of advantages. The material immediately surrounding the weld is never annealed because of the extremely low heat affected zone and quick cooling after welding. Due to the lack of mechanical stress during the welding process, parts rarely exhibit deformation or integrity problems.

With its high accuracy and ability to work on various metals, laser welding may reach areas inaccessible to conventional welding methods without ever touching the material. It is also highly controllable and there's little scrap involved.

In Laser cutting laser is used in the process of laser cutting to evaporate materials, creating a cut edge. Although it was originally only utilized in industrial manufacturing settings, today it is being employed in small firms and by amateurs. The process of

laser cutting involves most frequently using optics to focus the output of a high-power laser. The laser beam is guided to the material using laser optics and CNC (computer numerical control). Using a motion control system, a commercial laser for material cutting follows a CNC or G-code of the design that needs to be cut onto the material. The material is exposed to the concentrated laser beam, which causes it to either melt, burn, vaporize, or be blown away by a jet of gas leaving an edge with a high-quality finish. For laser cutting, there are three primary types of lasers. For cutting, drilling, and engraving, use a CO₂ laser. The only difference between the neodymium (Nd) and neodymium yttrium-aluminum-garnet (Nd: YAG) lasers is their intended use. Nd is employed for monotonous tasks that call for high intensity but little repetition. In general Laser cutting is classified into 4 types laser vaporization cutting, laser melting cutting, laser oxygen cutting, laser scribing, and rupture control

CHAPTER 4

MATERIALS AND METHODS

4.1 CORTEN STEEL

Corten A588 grade steel is well-known for its corrosion-resistant properties, and it is more sustainable alternative than any other for countering corrosion's negative effects. This was initially created to challenge corrosion of railroad coal wagons without the need for extra painting or layering. Corten A588 steel has a corrosion tolerance of 1 to 7 times than that of high carbon steel coating or galvanizing, which is customarily needed to pre-serve carbon steel. The Following Table illustrates the chemical composition of COR-TEN steel.

Table 4.1: Chemical Composition of Corten Steel A588 grade.

Element	Percentage	Element	Percentage
C	0.12	Al	0.018
Si	0.31	Co	0.006
Mn	0.36	Cu	0.249
P	0.106	Ti	0.004
S	0.001	V	0.003
Cr	0.5	W	Less than 0.01
Mo	0.021	Fe	Remainder
Ni	0.197		

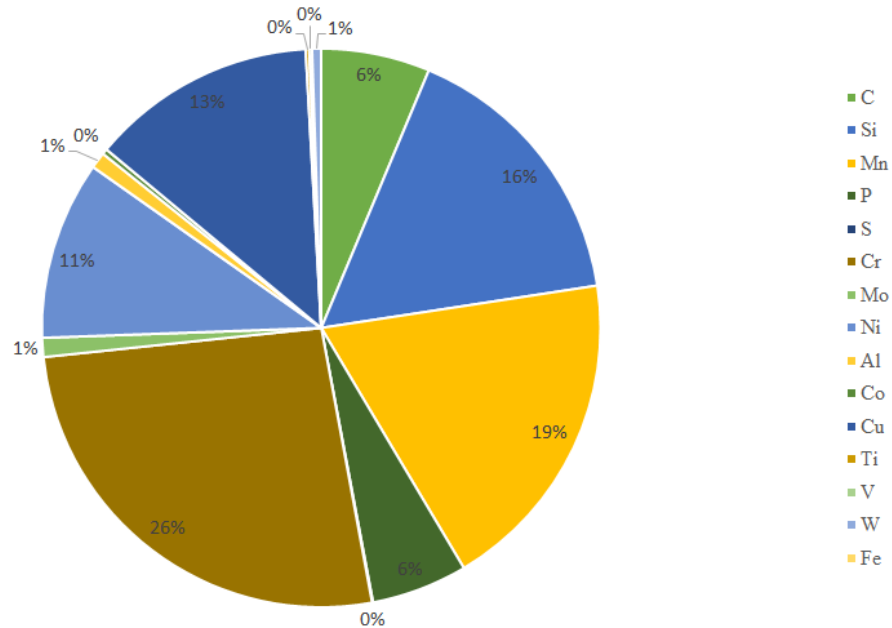


Fig: 4.1 : Chemical Composition of Corten Steel A588

4.2 BEAD-ON-PLATE WELDING ON COR-TEN PLATES

The Sample is polished and Bead-on-plate weld is performed in order to identify optimum weld parameters. The following table explains the parameters used to perform bead-on-plate for both the samples. Upon performing the bead on plate welding, with the parameters mentioned above, we get to understand the suitable and optimum parameters required to weld the material. The Parameter chosen to continue with Laser Butt-Welding is given in table 3. One key factor to consider when welding Cor-ten steel is the presence of copper in the material. Copper can help to improve the corrosion resistance of the steel, but it can also affect the welding process. When exposed to high temperatures, copper can vaporize and form porosity or other defects in the weld. To avoid this issue, it is important to use a laser with a wavelength that is well-absorbed by the material, and to carefully control the welding parameters to avoid overheating. Hence, the process of Bead-on-plate is conducted to avoid and minimize defects of these fashion. The laser beam rapidly heats the material, causing it to melt and flow together. The molten material then solidifies, creating a strong bond between the two

pieces. When welding Cor-ten steel using laser welding, it is important to consider several factors. These include the thickness and composition of the material, the type of laser being used, and the welding parameters. The plates of thickness 1.6mm and 3mm, are then welded as per the optimized parameter.

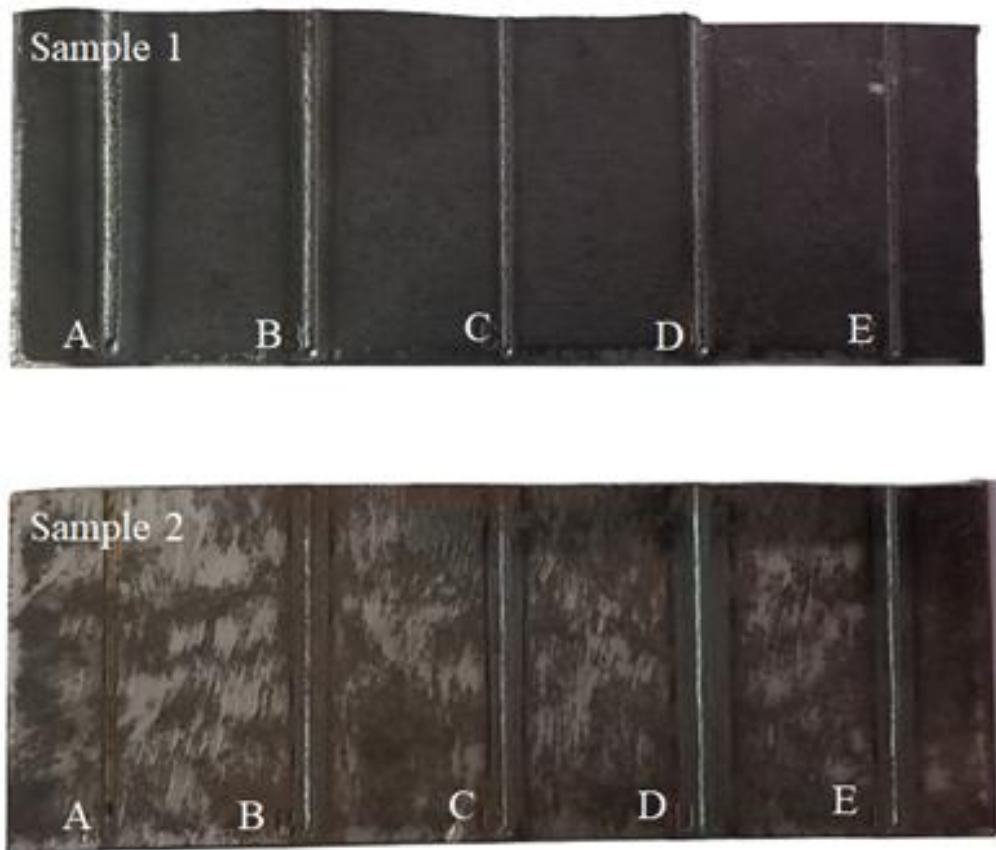


Fig: 4.2 : Samples after performing Bead-on-plate welding

The following table consists of the process parameters that have been used for the Bead on Plate welding to determine the optimized parameters for the weld.

Table 4.2 Parameters used for Bead-On-Plate Welding (Thickness:1.6mm)

Sl. No	Initial Speed (mm/s)	Max.Speed (mm/s)	Acceleration (mm/s)	PWM Freq.(hz)	PWM duty cycle(%)	DAC power (%)
A	10	10	45	45	50	40
B	8	8	45	45	50	55
C	7	7	45	45	50	50
D	6	6	45	45	50	60
E	12	12	45	45	50	70

Table 4.3 Parameters used for Bead-On-Plate Welding (Thickness: 3mm)

Sl. No	Initial Speed (mm/s)	Max.Speed (mm/s)	Acceleration (mm/s)	PWM Freq.(hz)	PWM duty cycle(%)	DAC power (%)
A	5	5	45	45	75	75
B	8	8	45	45	75	70
C	12	12	45	45	75	60
D	10	10	45	45	75	65
E	8	8	45	45	75	50

Table 4.4 The optimized parameters for Butt Welding.

Welding Source	Laser Welding
Speed	5 mm/s
Frequency	39 Hz
Power	85% 600W



Fig: 4.3 : Fanuc Robot used for Laser Operation and the Teach Pendant Used to control the arm.

4.3 LASER BEAM WELDING OF CORTEN STEEL PLATES:

The laser beam rapidly heats the material, causing it to melt and flow together. The molten material then solidifies, creating a strong bond between the two pieces. When welding Cor-ten steel using laser welding, it is important to consider several factors. These include the thickness and composition of the material, the type of laser being used, and the welding parameters.

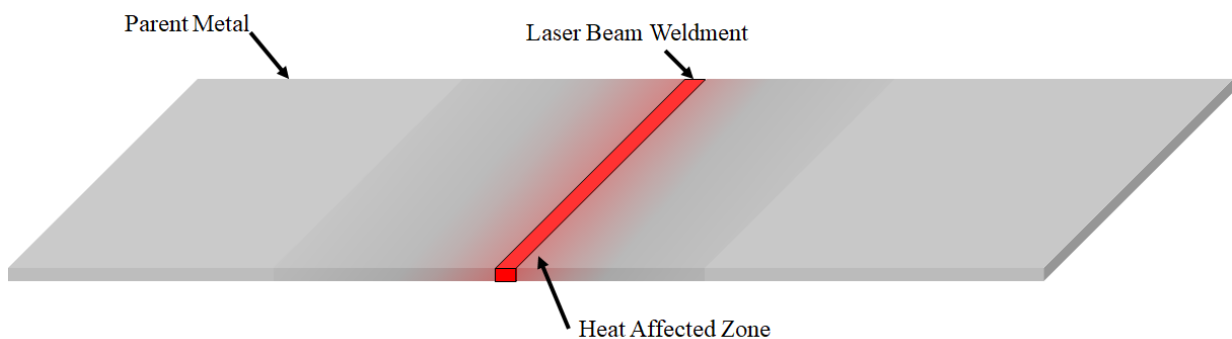


Fig: 4.4 : Schematic Diagram of the zones in Laser Beam Welded Steel.

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 MICROSTRUCTURE ANALYSIS

Microstructure analysis of laser weldments involves examining the characteristics of the weld's microscopic structure, such as its grain size, crystallographic orientation, and the presence of defects such as pores and cracks. Microstructure analysis of laser weldments typically involves examining the weld using various imaging techniques, such as scanning electron microscopy, transmission electron microscopy, and optical microscopy. These techniques can be used to determine the grain size, crystallographic orientation, and the presence of defects in the weld. The microstructure of a laser weldment can have a significant impact on its mechanical properties, such as its strength and ductility. Therefore, microstructure analysis is an important tool for optimizing laser welding processes and ensuring the quality and reliability of welded structures.

From the Microstructural Analysis, the presence of two distinct regions were observed in the very narrow HAZ. The parent metal microstructure reveals Ferrite (light phase) and Pearlite (darker phase) microstructure as which is typically observed in low carbon low alloy steels. They are the Fine Grained HAZ (FGHAZ), and the Coarse Grained HAZ (CGHAZ). It is noted that because of the high heat emitted by the laser beam, the parent metal has undergone recrystallization, exhibiting clear grain boundaries. The size of the grains in the HAZ region is in the vicinity of 5-8 microns. Whereas, the weld zone has attained high temperature and hence exhibit finer ferrite grains (Lesser than 5 microns) with coring than found in HAZ. Hence it can be concluded that in the regions where there was higher heat during the welding process, the grains are finer.



Weld Zone

Heat Affected Zone

Base Metal

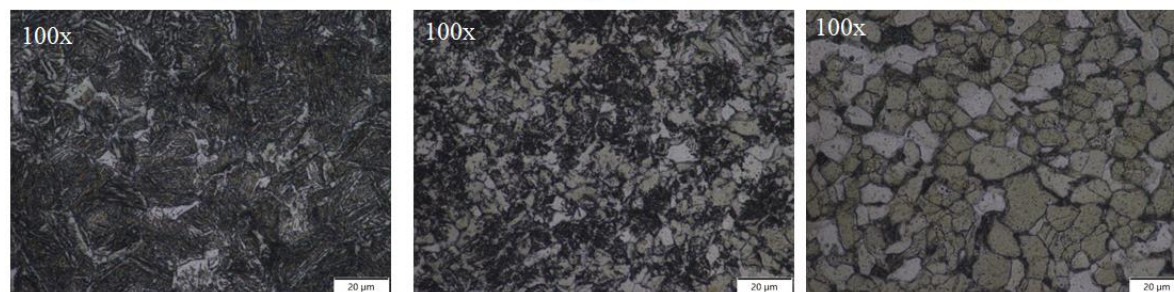


Fig: 5.1 The Microstructure Images of the Sample 1 in two magnifications (10x and 100x) illustrating differences after Laser Welding has been done.



Weld Zone

Heat Affected Zone

Base Metal



Fig: 5.2 The Microstructure Images of Sample 2 in two magnifications (10x and 100x) illustrating differences after Laser Welding has been done.

5.2 TENSILE TEST

Upon applying a Peak Load in the vicinity of 16.8 kN, and the peak stress applied was in the vicinity of 550 MPa for the First Sample and as for the second sample, the peak load applied was in the vicinity of 32 kN and the Peak Stress in the vicinity of 575 MPa, the final result of both the samples, of thickness 2mm and 3mm, infer that upon conducting the test that there failure is noticed only at the parent material, this means, The weld bead was strong enough to not have any failure upon application of load. One reason for the high tensile strength of laser welding is that the heat input is very localized and controlled. This means that the metal being welded is exposed to high temperatures for a short period of time, minimizing the heat-affected zone (HAZ) in the surrounding material. The heat-affected zone is the area around the weld where the metal has been heated but not melted, and which can be prone to micro cracking and reduced strength.

Sample 1: (T1, T2, T3)

Testing Method: ASTM B557M:2015

Environmental Temperature: 23+ 5°C

Table 5.1: Mechanical Testing - Tensile Test (1.6mm)

TESTED PARAMETERS	T1	T2	T3
Peak Load (kN)	16.91	16.63	16.82
Peak Stress (MPa)	554.5	546.5	552.2
Result	Failed at Parent Material	Failed at Parent Material	Failed at Parent Material

Sample 2: (T1, T2, T3)

Testing Method: ASTM B557M:2015

Environmental Temperature: 23+ 5°C

Table 5.2: Mechanical Testing - Tensile Test (3 mm)

TESTED PARAMETERS	T1	T2	T3
Peak Load (kN)	32.96	32.49	32.46
Peak Stress (MPa)	576.9	569.4	585.1
Result	Failed at Parent Material	Failed at Parent Material	Failed at Parent Material

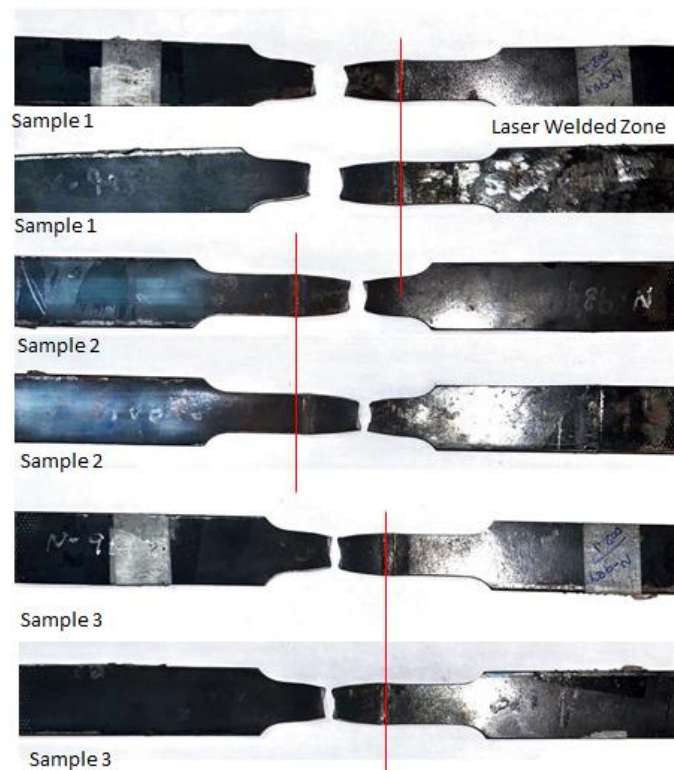


Fig: 5.3 Tensile Test Samples

5.3 HARDNESS TEST:

Hardness testing is an important quality control tool used in manufacturing to ensure that materials are consistent and meet the required specifications. It can help identify defects in the material, such as inconsistencies in the alloy or improper heat treatment. It can provide an indirect measure of the strength of a material. There is a correlation between hardness and strength, which means that the hardness of a material can be used to estimate its strength. Hardness testing is utilized to determine the suitability of a material for a particular application. For example, if a material needs to withstand wear and tear or impact, a harder material would be required.

The hardness of the weld zone is more than the hardness in the HAZ and Base Metal. Primarily, this is because of the high heating followed by the rapid cooling that takes place in the weld zone, resulting in the formation of Martensite structures, the hardness of which is higher than the base metal. Moreover, the presence of some remaining delta-ferrite in the martensitic weld structure is responsible for the minor reduction of hardness in certain areas of the weld. The formation of FGHAZ (Fine Grain HAZ) and CGHAZ (Coarse Grain HAZ) in the HAZ region, are responsible for the minute changes in the hardness of those regions. For the Corten steel samples of thickness 1.6mm, the hardness was increased by 75% from the Base Metal Region to the HAZ region, whereas a significant increase in hardness by 140% was noted in the weld region. While the percentage change in hardness of the second sample of 3mm thickness was noted to have similar trends. The hardness of the base metal of Corten steel is in the vicinity of 178 HV, If there is a minimal change between the Hardness value of Base Metal and Weld Zone, it implies that there is lower Martensite formation in the region. The obtained hardness results prove right because if the value is higher than 450, then the weld material would be brittle.

Sample 1:

Sample Thickness: 1.6mm

Test Load- 0.1HV

Environmental Temperature- 23+5°C

Table 5.3: Mechanical Testing – Vickers Microhardness Test (1.6mm)

BASE			HAZ		WM	HAZ		BASE		
1	2	3	4	5	6	7	8	9	10	11
172	176	183	281	302	417	310	274	178	173	169

Sample 2:

Sample Thickness: 3 mm

Test Load- 0.1HV

Environmental Temperature- 23+5°C

Table 5.4: Mechanical Testing – Vickers Microhardness Test (3mm)

BASE			HAZ		WM	HAZ		BASE		
1	2	3	4	5	6	7	8	9	10	11
174	170	181	293	314	420	307	300	187	182	176

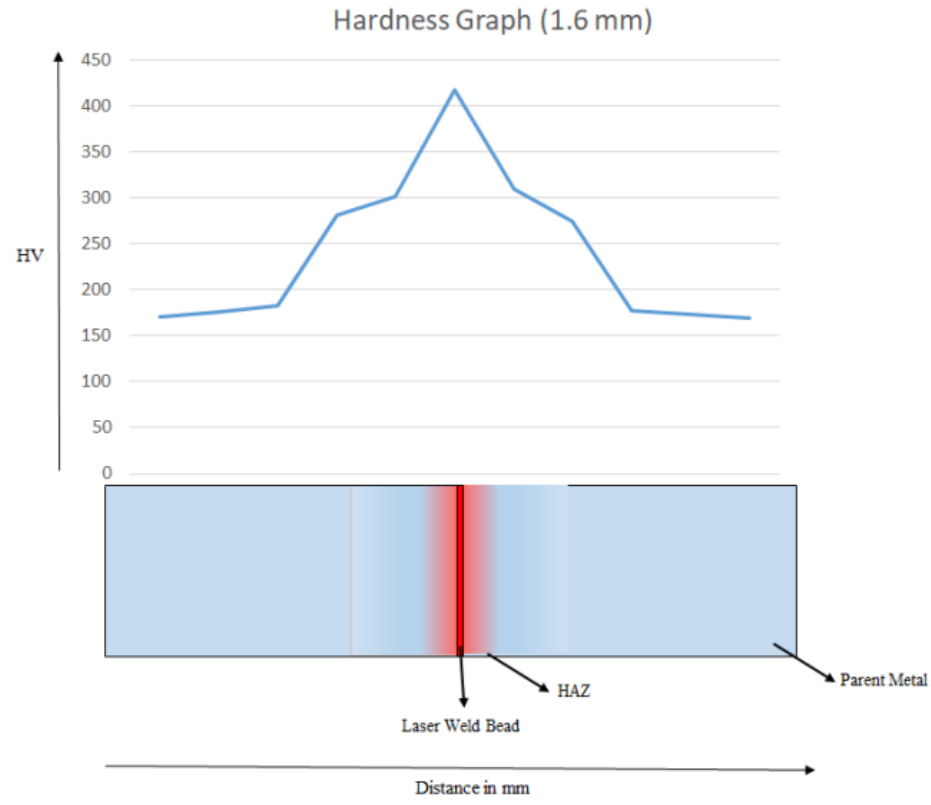


Fig: 5.4: Hardness Characteristics of Laser Beam Welded Corten Steel Sample of 1.6mm thickness.

The hardness of the weld zone is more than the hardness in the HAZ and Base Metal. Primarily, this is because of the high heating followed by the rapid cooling that takes place in the weld zone, resulting in the formation of Martensite structures, the hardness of which is higher than the base metal. Moreover, the presence of some remaining delta-ferrite in the martensitic weld structure is responsible for the minor reduction of hardness in certain areas of the weld. The formation of FGHAZ (Fine Grain HAZ) and CGHAZ (Coarse Grain HAZ) in the HAZ region, are responsible for the minute changes in the hardness of those regions. For the Corten steel samples of thickness 1.6mm, the hardness was increased by 75% from the Base Metal Region to the HAZ region, whereas a significant increase in hardness by 140% was noted in the weld region. While the percentage change in hardness of the second sample of 3mm thickness was noted to have similar trends. The hardness of the base metal of Corten steel is in the

vicinity of 178 HV, If there is a minimal change between the Hardness value of Base Metal and Weld Zone, it implies that there is lower Martensite formation in the region. The obtained hardness results prove right because if the value is higher than 450, then the weld material would be brittle.

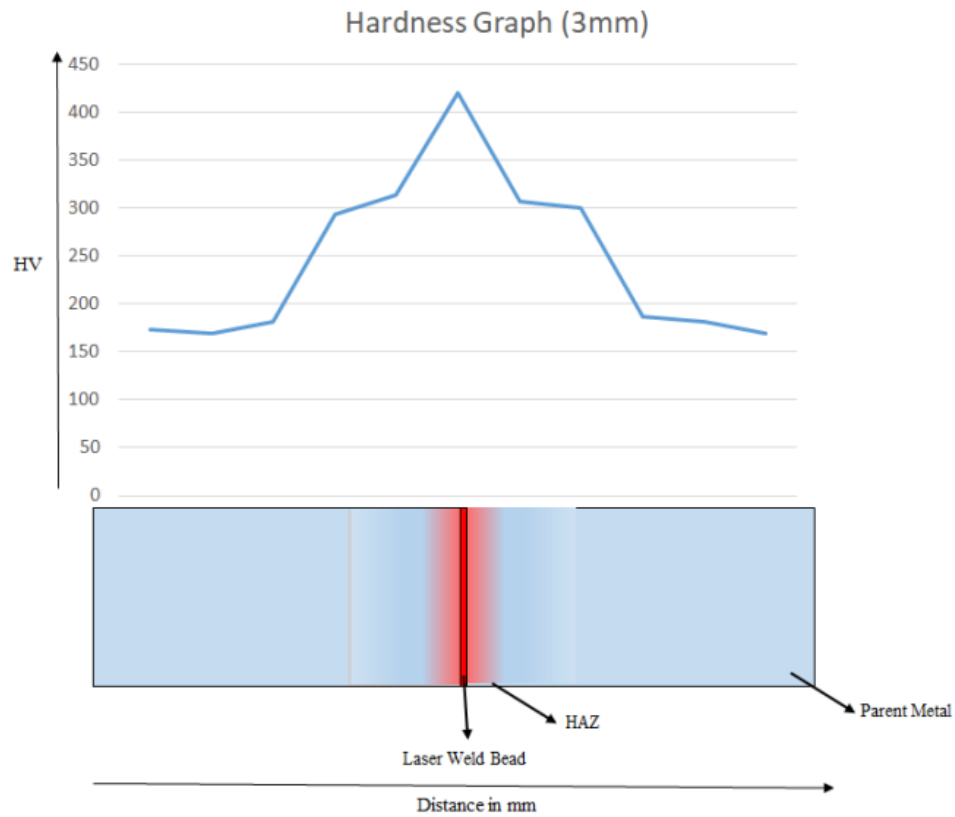


Fig: 5.5: Hardness Characteristics of Laser Beam Welded Corten Steel Sample of 3mm thickness.

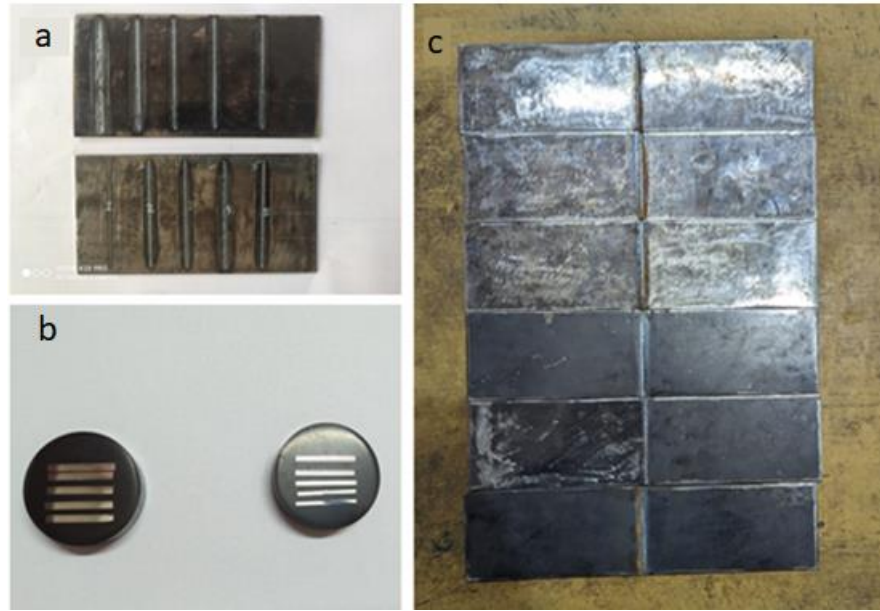


Fig: 5.6 1 The Samples of Bead-On-Plate welding on Cor-ten Steel. Fig 2: The Cut, Polished and molded samples of Bead-on-Plate welded Samples shown in Fig 1. Fig 3: The Butt-Welding done of samples, using Laser Beam Welding.

CHAPTER 6

SUMMARY AND CONCLUSIONS

Laser welding has now become a very instrumental part in machining and micro machining, especially in aircraft industries and shipbuilding industries where the manufacturing process must be done with utmost and micron level precision. The efficient utilization of Lasers in the industry in the recent times, which is gradually replacing the conventional methods is the novelty expressed.

Lasers are easy to handle, and easy to automate hence manufacturers can easily incorporate laser operation into their production plants. The efficiency of lasers in the field of manufacturing and production would create a paradigm shifting effect in the future of the manufacturing industry in this generation of Industry 4.0.

The Laser welding process parameters for 1.6 and 3mm thick Corten steel plate is optimized. The optimized process parameters for laser welding are a speed of 5 mm/s, frequency of 39 Hz and power of 600W is obtained by carrying out bead on plate (BOP). The mechanical and microstructural properties of these laser welded joints are summarized.

The average hardness of the base metal (BM) of Corten steel is 175 HVN. The maximum hardness of the weld zone (WZ) is 417 HVN and 420 HVN which is comparatively higher than the hardness in the HAZ and Base Metal (BM) for 1.6 and 3mm thick plates respectively. This is due to high concentrated heat input applied on the weld zone and followed by rapid cooling resulting in formation of a Martensitic structure. The average hardness in the heat affected zone (HAZ) is in the vicinity of 290 HVN and 302 HVN for 1.6 and 3mm thick plates respectively. This is due to the high heat input followed by slow cooling resulting in formation of FGHAZ (Fine Grain HAZ) and CGHAZ (Coarse Grain HAZ) in the HAZ.

The optical microstructure of the Corten steel base metal reveals Ferrite (light phase) and Pearlite (darker phase) which is typically observed in low carbon - low alloy steels. Two distinct regions named Fine Grained HAZ (FGHAZ) and Coarse Grained HAZ (CGHAZ) are observed in the narrow HAZ. Recrystallization of grains in the HAZ occurs due to the high concentrated heat induced by the laser welding process followed by slow cooling. Clear grain boundaries with varied grain size of vicinity of 5-8 microns. Widmanstatten patterned Martensitic structures are formed in the weld zone (WZ) which is due to the high concentrated heat input followed by rapid cooling in the coring region of the weld.

Upon applying a Peak Load in the vicinity of 16.8 kN, and the peak stress applied was in the vicinity of 550 MPa for the First Sample and as for the second sample, the peak load applied was in the vicinity of 32 kN and the Peak Stress in the vicinity of 575 MPa. The yield strength being around 340 kgf/mm². Upon conducting the tensile stress, the final result of both the samples, of thickness 1.6 mm and 3mm, infer that upon conducting the test that their failure is noticed only at the parent material, this means, the weld bead was strong enough to not have any failure upon application of load. The reason for the high tensile strength of laser welding is that the heat input is very localized and controlled.

From the results obtained it can be concluded that the Laser Welding creates narrow Heat Affected Zone, higher weld strength, and an appealing weld bead which does not requires any finishing operation.

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ANNEXURE:

- Review paper has been presented in iCAM conference conducted by Sathyabama Institute of Science and Technology, Chennai on November 4th, 2022.
- Review paper titled "Application of Lasers in Industries and laser welding: A review" by J.R. Deepak, Anirudh R.P, Saran Sundar S has been published in Materials Today: Proceedings.
- Research paper titled "Microstructural and Mechanical property investigation of Corten A588 Grade Steel Laser Beam weld joint " by J.R. Deepak, Anirudh R.P, Saran Sundar S been presented in ICDTM conference conducted by Sastra University, Thanjavur on 9th April, 2023.

Microstructural and Mechanical property investigation of Corten A588 Grade Steel Laser Beam Weld Joint.

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Abstract

Corten steel is high strength, high corrosion resistant, low maintenance, and cost effective steel due to the presence of Ni, Cr elements alloyed to it. Corten Steel, when exposed to environment immediately forms a stable oxide (patina) layer which reduces corrosion, and hence it is commonly used in outdoor environments and other applications where other low-carbon steels would be inclined to corrosion. Laser Beam Welding (LBW) is extensively utilized in construction, railways and aerospace applications to join metals and alloys. In this research work, Corten A588 grade steel Laser Joints is prepared using a 3KW CO₂ Laser welding machine. Bead on Plate studies is carried out in 1.6 mm and 3 mm thick plate followed by which the Mechanical properties like hardness, tensile, bending and impact test is carried out and the microstructure of the LBW weld joints is investigated. The comparative advantages of choosing Laser Beam Welding over other welding process like Improved mechanical properties, microstructural properties, controlled heating, Narrow Heat Affected Zone (HAZ) and appealing weld bead formation makes it a better choice.

Keywords: Corten A588 Grade Steel, Laser Beam Welding, Bead on Plate, Mechanical Property, Microstructure

1. Introduction

Laser is a versatile technology which is used efficiently on various industrial applications for a wide range of materials. Laser beam can be focused up to 1/1000 of a millimeter. High precision, high speed, and high quality are a few advantages of laser technology. Laser machined surface is visually appealing and free from post-machining burrs. Laser technologies are highly effective and efficient when used in industries which has created a massive impact in manufacturing sector. The compatibility of this technology makes it extremely convenient to incorporate this technology very easily into industrial shop floors and assembly lines.

Laser welding has been widely used in various industries in areas such as car manufacturing, shipbuilding, and bridge construction due to its advantages in the implementation of high production, automotive processing, and creating a high-quality weld with little heat impact zones. Laser-based welding provides more strength in the joints, and also the laser is concentrated at the necessary point, hence high precision. Laser welding works by using laser radiation in order to melt the target material or workpiece down to a molten state and then the joining operation is done. There are no electrodes or fillers necessary for laser welding operation, therefore the material is not prone to contamination and deformation. Laser welding is so precise that it can form welds smaller than a millimeter. In laser welding, the heat affected zone is smaller and the total heat applied is much lower than traditional welding operations. Laser welding, also exhibits faster processing time, and is cost effective. It has greater production capacities too. Hence Laser Welding, is an emerging field where-in the production is done faster, with more accuracy and precision. There are different kinds of lasers that are used in the industries to perform various functions and operations. Laser sources like Ruby Laser, CO₂ Laser, Nd-YAG laser etc. are few of the laser sources that are generally used in the industry. Both pulsed and CW lasers are used for industrial applications. Nd: YAG (~10KW), CO₂ (~25KW) and COIL (~40KW) are some of the most commonly used high power lasers. The high monochromaticity and directivity of the laser gives the laser beam small wavelength dispersion and low divergence. Therefore, the laser can be focused to a very small spot size, resulting in very high luminance. As per the results of previous Laser Beam Welding Experiments done

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Prof. R. Venkatraman
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CERTIFICATE

THIS IS TO CERTIFY THAT

—◆ Mr. ANIRUDH R. P. ◆—

Student, School of Mechanical Engineering, Sathyabama Institute of Science and Technology, Chennai, India has presented a paper entitled "*Applications of Lasers in Industries and Laser Welding: A Review*", in the second International conference on "Advancements in Materials Science and Technology – iCAM 2022", organized by Sathyabama Institute of Science and Technology, Chennai, India in association with Alexander Dubček University of Trenčín, Slovakia, during November 02–04, 2022.

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Applications of lasers in industries and laser welding: A review

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ABSTRACT

Laser can be focused up to 1/1000 of a millimeter. Laser machining is clean, and free from post machining burrs. Laser technologies are highly effective and efficient in industries which has created a massive impact in manufacturing. Laser is versatile, it can be performed efficiently on a large range of materials, High precision, speed, and quality of laser machining are a few advantages of this technology. The compatibility of this technology makes it extremely convenient to incorporate into industrial lines. The utilization of Laser Technology to improve precision in production, increased automation substituting the conventional methods, which would have various drawbacks in reflected through this review paper. This review paper compiles the impact of various laser sources, industrial applications of laser on industries over conventional methods. It also summarizes the Laser Welding being used in the industries for precise manufacturing. The precision and quality of laser welding is also demonstrated by performing bead-on-plate weld on steel.

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1. Introduction

The involvement of Laser in industrial activities has been a paradigm-shifting technological advancement in the field of engineering. Lasers are used in Industries for applications like cutting metals and fabrics, cleaning metallic surfaces, altering the surface roughness, measuring dimensions, and also to weld metals with high precision. Laser welding is predominantly used in automobile and aeronautical industries which would require engineering works to be carried out with high precision.

Nowadays, Lasers are used for **High-Volume Laser Welding, Laser marking of components, and also Additive manufacturing** using Lasers. Lasers are also being used for the reworking of expensive metallic components that have undergone visible wear and tear. It has also played a pivotal role in the emerging field of MEMS (Micro Electro Mechanical Systems), Additive Manufacturing [28] and Nanotechnology. Lasers are used in drilling operations as well; laser drilling achieves a complete through-hole by vaporizing the target material in tiny layers [14]. The basic laser material processing (LMP) system consists of a high-power laser, a unit for beam delivery with a focusing arm, and a beam parameter monitoring unit connected to a CNC machine. Delivering and manipulating

laser beams into extremely complex structures and interior locations is a critical aspect of the LMP system. The method of transmission is determined by **wavelength, energy, power, beam diameter, divergence**, etc.

1.1. Advantages of Lasers in industries

- Lasers are extremely accurate; an advanced laser beam can be focused down to **1/1000 of a millimeter**. The laser-based operations can be done with micro precision. Since laser possesses these advantages, it's widely used in Micromachining, Micro production, 3D printing [28] & Nanotechnology. Machining using lasers is clean and **free from post-machining burrs**, making the entire process convenient.
- Lasers can easily be incorporated into production lines in order to achieve a more standardized operation. Manufacturing using lasers results in **shorter cycle times, lower maintenance**, and **relatively cost-effective production** [15].
- Laser is versatile, it can be performed efficiently on a large range of materials like fabric, glass, and metal. It's also used in the healthcare industry especially in the field of dermatology [17] & healthcare because of its micron-level accuracy.
- Lasers have a reduced effect on the environment, making them more energy efficient. Implementing laser technology would reduce carbon emissions.

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- Lasers are compact, hence more economical production lines. Automated Laser machines are instrumental in creating safer manufacturing floors facilitating elimination of risky manual processes. The Fig. 1 shows the various types of laser sources used for various industrial applications.

2. Types of Lasers used in industries

2.1. Industrial applications of Laser

- Laser Marking:** Laser Marking is increasingly used in industries to imprint unique identification (UID) numbers of machine parts and products. Laser markings are highly durable and also withstand various cycles of sterilization in industries. Laser engraving can be applied on surfaces that are flat or curved. The Fig. 2 shows the various types of laser sources and its industrial applications.
- Surface Texturing:** Lasers are beneficial in creating patterned or textured microstructures on the surface of the components or products that would directly affect their physical performance. It would enhance the surface and is considered a viable and efficient way to modify the interaction between the surface for better lubrication and controlled friction. [13]
- Laser Drilling:** Laser drilling is generally done by either melting or vaporizing the target material or the workpiece material through the absorption of energy from a concentrated laser beam. Usually, the melting process is considered more favorable because the energy required for melting is just 25 % of that required for vaporizing. [14]
- Laser Cutting:** Laser cutting employs are focused high-power beam to remove materials rapidly and produce very fine cuts. Lasers are capable of slicing through dense materials with relative ease, especially in materials like Titanium and Steel. Laser cutting is better than conventional cutting processes because of the speed at which the process is carried out, and the micrometer level precision as well as repeatability. [20] The Table 2 show the applications of Laser in various process applications.
- Laser Hardening:** Laser Hardening is a heat treatment process that is used to improve the durability and strength of component surfaces. It employs the use of high-powered diode lasers that apply energy to heat the localized area of the component's surface. Laser hardening offers a lower risk of warping and cracking and also the advantage of greater precision and accuracy with broader material flexibility. [27]
- Laser Welding:** Laser welding has been widely used in various industries in areas such as car manufacturing, shipbuilding, and bridge construction due to its advantages in the implementation of high production, automotive processing, and creating a high-quality weld with little heat impact zones. Laser-based welding provides more strength in the joints, and also the laser is concentrated at the necessary point, hence high precision. Laser welding works by using laser radiation in order to melt the target material or workpiece down to a molten state and then the joining operation is done. There are no electrodes or fillers necessary for laser welding operation, therefore the material is not prone to contamination and deformation. Laser welding is so precise that it can form welds smaller than a millimeter. [24] The Table 1 shows the various sources of laser and its Industrial Applications.

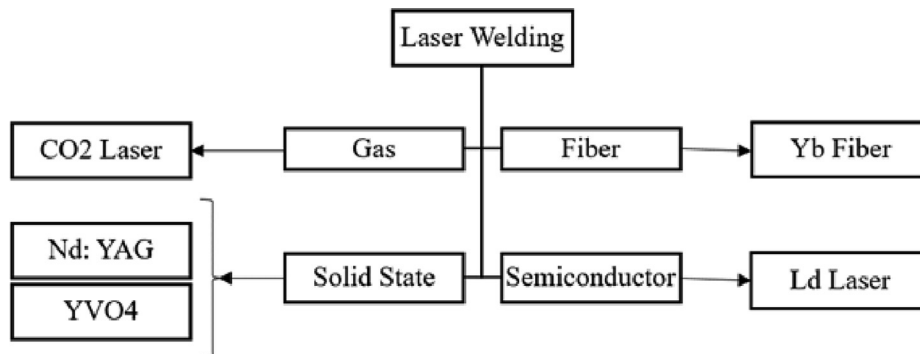


Fig. 1. The different kinds of laser source used in laser welding.

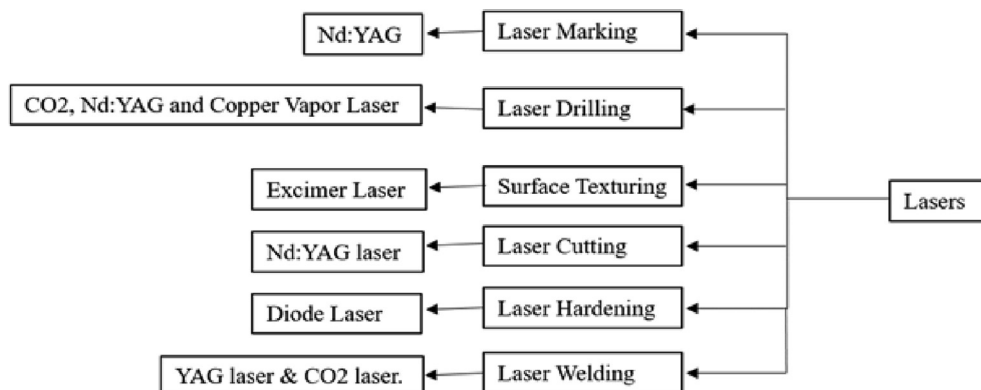


Fig. 2. Types of lasers used in laser manufacturing operations.

Table 1

Laser Sources and its respective Industrial Applications.

Type of Lasers	Wavelength	Applications
Nd:YAG(Nd-Yttrium Aluminium Garnet)	1064 nm 532 nm in second harmonic 355 nm in third harmonic	Marking applications and micro processing.[17]
Nd:YVO4(Yttrium Vanadate)	1064 nm	Used in applications that require high peak and stable beam power.
Yb: Fiber (Ytterbium)	1090 nm	High average power and excellent cooling efficiency make it useful for marking operations on metals and plastics.
CO2	10.6 μ m	Used for marking, etching, and cutting operations. [17]
He-Ne	630 nm	Measuring operations
Excimer	193 nm	Used in Lithography and surface texturing, also for optometry.
Argon	488–514 nm	Used primarily in biomedical-related research.
Copper Vapor Laser	510.6–578.2 nm	Commonly used for machining and laser cutting operations.[21]
Diode Laser	810–1064 nm	Laser Hardening operations

Table 2

Specific Applications of Laser.

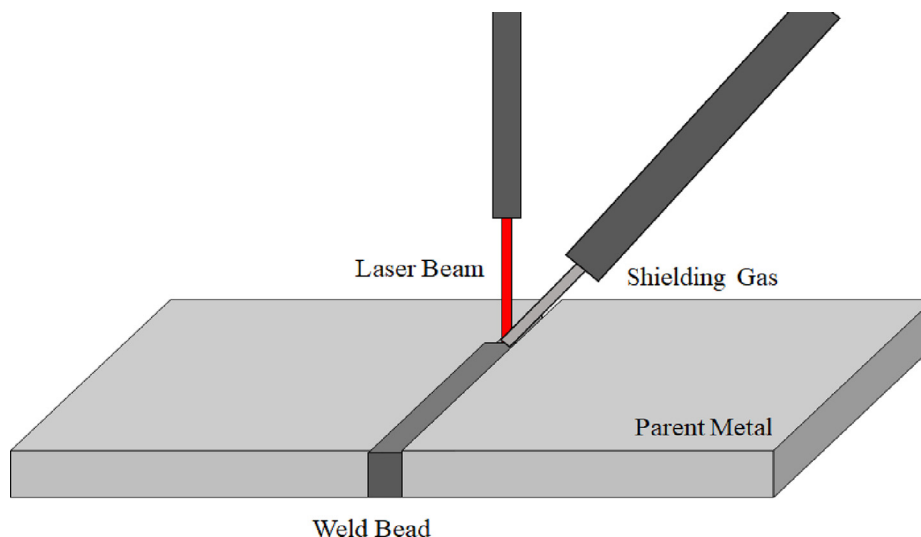
Applications	Operation involved	Laser Source used for the application
Laser Marking	Used to engrave a Unique Identification number onto the machine parts.[29]	An Nd-YAG laser is generally used for marking operations. They emit invisible near IR beams with a wavelength of 1064 nm.
Surface Texturing	Formation of patterned microstructure on the surfaces of components to prevent friction-based wear and tear.[22]	Excimer laser, a prominent UV laser used for its micrometer precision is generally used for lithography and surface texturing. [16]
Laser Drilling	It's generally done by either melting or vaporizing the target material through the absorption of energy from a concentrated laser beam. [14]	CO2, Nd-YAG, and Copper Vapour Laser are generally used.
Laser Cutting	Employs a focused high-power beam to remove materials in succession and produce fine cuts.[29]	Nd-YAG laser and is primarily used for laser cutting operations.
Laser Hardening	It employs a high-powered diode that applies energy to heat a particular area of the component's surface.	Diode Lasers are used for this process.
Laser Welding	It works by using laser beam in order to melt the target material down to a molten state and then joined. [1]	For solid state welding YAG laser is used, and for gas- CO2 laser is used. [26]

2.2. Disadvantages of Laser

- In order to perform certain laser operations, the operator must require a certain amount of expertise. An experienced operator should be well versed and equipped with knowledge of different material compositions in order to perform the operations in a very efficient manner.

- Hence acquiring proper manpower for carrying out a laser-based manufacturing operation is a task.
- The materials upon which the laser is used tend to get evaporated quickly.

Eg: Upon cutting plastics, evaporation tends to occur. If the device is set up incorrectly, and if the operator is unaware of the material properties then it would cause significant damage.

**Fig. 3.** Schematic diagram of laser welding on 2 metals.

- Another added disadvantage is the limitations to the metal thickness. Laser operations like laser cutting can be used on a wide variety of metals but the thickness of the metal would be in the range of 15 mm to 20 mm.
- To procure a laser machine, the initial investment is significantly high. When it comes to laser welding, the common defects include Gas Entrapment, Porosity and Cold Bonding.

Table 3

Review of Literature.

S. No.	Material Used	Laser Used	Inference	References
1	Mg Alloy	CO ₂ Lasers & Nd:YAG lasers	Mg Alloys and other dissimilar metals and composites would be welded in the future because of its low cost, high quality, repeatable. Easy handling and control of Nd: YAG lasers through fiber optic delivery provides welding capabilities for complex geometries where 3D welding can be performed. [18]	[1]
2	Ti6Al4V (Titanium Alloys)	Lumonics JK760TR Nd: YAG pulsed laser	You could see that peak performance is the most important parameter in determining penetration depth equal to pulse-to-pulse energy duration. If the peak power is too high, the temperature of the workpieces will exceed the vaporization point of the Ti6Al4V alloy, which promotes the formation of craters on the surface materials.	[2]
3	Low Carbon DC 04 Steel to 6000 series Aluminium	YAG lasers	Flawless welds were obtained on overlapping Al-steel joints. Welds obtained in the aluminum-on steel configurational ways show cracks at the weld-steel interface.	[3]
4	5000 & 6000 series alloys	Nd:YAG lasers	The easy handling and control of Nd: YAG lasers using fiber optic feed provides welding options for complex geometries where overhead, vertical, horizontal or all position welding can be done effectively and efficiently. Process control and monitoring is required for such applications.	[4]
5	Ti-Al dissimilar metal welding.	CO ₂ Laser	A melt line with a fine microstructure was formed by diffusion of the Si element from the weld pool into the semi-molten zone at the solid/liquid interface.	[5]
6	AISI 304 stainless steel plate with AISI 316 L powder as filler.	Ar Laser	Variance analysis showed that laser power, translation speed, feed rate, laser spot diameter affected the penetration depth and track width, but porosity is only affected by laser spot diameter and carrier gas flow.	[6]
7	Laser Welding Of Titanium Alloy Ti6al4v Using A Disk Laser	Disk Laser	The weld balls were made on Ti6Al4V titaniumalloy (Grade 5 acc ASTM B265) 2.0 mm thick sheets at different laser power and melting speed to simulate butt welding without additional material.	[7]
8	The Study on Mechanical Strength of Titanium-Aluminum Dissimilar Butt Joints by Laser Welding-Brazing Process	–	Laser welding - butt brazing of Ti6Al4V and 5A06 sheets with a thickness of 1.5 mm the configuration was made by focusing the laser beam on the 5A06 aluminum alloy side without filler metal. The effects of laser offset, welding speed, and laser power on spread length, IFZW, fracture roughness, IMC thickness, and joint tensile strength were investigated.	[8]
9	Laser welding of light metal alloys: Aluminium and titanium alloys	Nd:YAG, CO ₂ , fibre laser, diode laser can be used	The process parameters of Aluminium and Titanium alloys have been studied and tabulated in detail.	[9]
10	Improvement weldability of dissimilar joints(Ti6Al4V/Al6013) for aerospace industry by Laser beam welding	Ytterbium fiber lasers	The experiments performed and the results obtained in this work were intended to investigate and optimize the weldability of a dissimilar joint of AA6013 and Ti-6Al-4 V obtained by a laser welding process.	[10]
11	Review on Laser Welding of Titanium Alloy	Co2 Laser,Nd: Yag Laser, Disk Laser, Diode Laser, Fiber Laser	Gaussian mode laser welding required high laser power and high welding speed, while donut mode required high laser power and low welding speed for efficient laser beam welding. The residual stress development magnitudes were found to be higher in the donut mode compared to the Gaussian mode of laser welding.	[11]
12	Impact Of Process Parameters Of Laser Welding On The Mechanical Properties Of Ti6al4v A Review	CO ₂ Laser	Higher welding speed, energy input and welding performance, are beneficial for reduced porosity, reduced under fill, good bead geometry and optimal hardness	[12]

3. Need for Laser welding

Laser welding is now prevalent in the field of Automobile and Aeronautical field, the primary advantage of laser welding over primitive welding methods is as follows:

- Increased Production rates
- Reducing Production Cost
- Accuracy
- Repeatability
- High Quality weld (with micron level precision)

Laser Welding has high power density on the order of **1 MW/cm²** resulting in small heat affected zones, the weld spot size can vary between **0.2 and 13 mm**. Its capable of welding wide variety of materials notably – **Carbon steels, HSLA steels, aluminium, titanium, stainless steel.** [23]

The common types of lasers used are:

- Solid state lasers (ruby lasers, neodymium in yttrium aluminum garnet (Nd: YAG).
- Gas Lasers such as helium, nitrogen, carbon dioxide.
- Laser welding systems are automated with the use of Computer Aided Manufacturing based on CAD designs with software's such as AlmaCAM. The Fig. 3 shows the schematic diagram of laser welding operation of two metal plates.

4. Review of Literature

The following Review of Literature Table 3 summarizes the research work done that has been previously in the field of Laser Welding on different materials.

5. Case study of Laser welding on Railway steel

Using a Laser Welding machine, a bead-on-plate welding had been done on railway steel in order to check its advantages and assess the nature of the weld material. Upon conducting the welding process using Laser-Beam Welding, it is evident that the weld is precise, because of the focused welding done, the heat affected zone is also much lesser in Railway steel.

In general, a bead on the board reduces the likelihood of gaps, misalignments, and other problems that could cause welding errors or reduced strength. Additionally, it is occasionally per-

formed as a first step to establish parameters acceptable for full penetration butt welding.

If you use bead welding on a plate, you can easily get identical or very similar welding conditions to compare results (Eg. with or without flux activated), but if butt welding is done, you should pay attention to gap, groove and misalignment. If one of these changes, the welding conditions will be different and the significance of the experimental results for comparison will be lost. The Fig. 4 shows the bead on plate laser welding of 3 mm thick plates using different weld parameters.

6. Summary

The conventional methods of marking, surface texturing, drilling, welding have been substituted by the laser technology because of massive advantages that facilitates the manufacturing process to a very large extent. Laser technologies are incorporated into production lines with comparable convenience to make operations more standardized. The types of lasers used in each operation is studied and the process parameters generally considered for Laser Welding is also considered. A sample of Railway Steel was also done to study the characteristics of laser welding and its various advantages .

7. Conclusion

This paper portrays the advancements in the field of automation, manufacturing with the incorporation of laser. Laser welding has now become a very instrumental part in machining and micro machining, especially in aircraft industries and shipbuilding industries where the manufacturing process must be done with utmost and micron level precision. The efficient utilization of Lasers in the industry in the recent times, which is gradually replacing the conventional methods is the novelty expressed. This paper also discusses the advantages of laser welding over conventional welding methods. Lasers are easy to handle, and easy to automate hence manufacturers can easily incorporate laser operation into their production plants. The efficiency of lasers in the field of manufacturing and production would create a paradigm shifting effect in the future of the manufacturing industry in this generation of Industry 4.0.

CRediT authorship contribution statement

J.R. Deepak: Conceptualization, Supervision, Writing – original draft. **R.P. Anirudh:** Writing – original draft. **S. Saran Sundar:** Writing – original draft.

Data availability

No data was used for the research described in the article.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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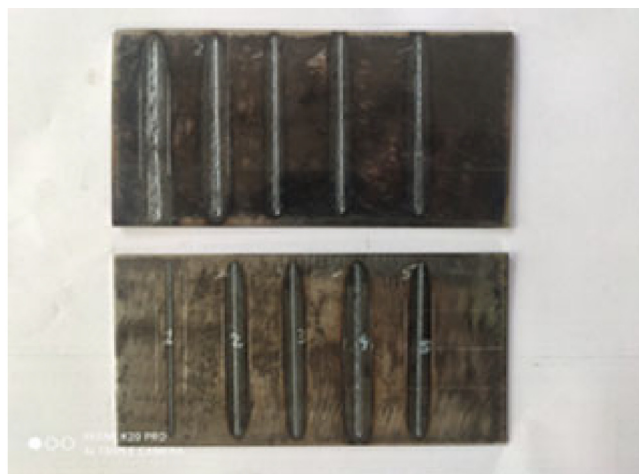


Fig. 4. Sample of Bead-on-plate welding using Laser Beam Welding.

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