A Literature Review on Electron Beam Welding

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Abstract- *Electron beam welding is a fusion welding process where electrons are generated by an electron gun and it is accelerated to high speeds using electrical fields. This high speed stream of electrons is tightly focused on the weld spot using magnetic fields and applied to the materials to be joined. This beam of electrons creates kinetic heat as it impacts with the workpieces, causing them to melt and bond together,it is widely used in the Aerospace and Defense industries mainly due to the Narrow Fusion Zone generated as less amount of metal is melted during joining which leads to less distortion and less amount of heat.The Electron Beam Welding process is complex in nature and is controlled by large number of parameters. Welding Input Parameters plays a vital role in determining the quality of weld. Parameters such as Accelerating Voltage,Beam Current, Depth of Penetration,Beam Focal Diameter and Welding Speed are part of the Electron Beam Parameters. This paper reviews various researches made in Electron Beam Welding process and conclude with factors influencing the high quality of Weld.*

Keywords- Electron Beam Welding, Fusion Welding, Welding Parameters, Low distortion.

I. INTRODUCTION

Electron Beam Welding is a welding process utilizing a heat generated by a beam of high energy electrons. The electrons strike the work piece and their kinetic energy converts into thermal energy heating the metal so that the edges of work piece are fused and joined together forming a weld after Solidification. The process is carried out in a vacuum chamber at a pressure of about $2*10^{-7}$ to $2*10^{-6}$ psi (0.00013 to 0.0013 Pa). Such high vacuum is required in order to prevent loss of the electrons energy in collisions with air molecules. The electrons are emitted by a cathode (electron gun). Due to a high voltage (about 150 kV) applied between the cathode and the anode the electrons are accelerated up to 30% - 60% of the speed of light.

Kinetic energy of the electrons becomes sufficient for melting the targeted weld. Some of the electrons energy transforms into X-ray irradiation. Electrons accelerated by electric field are then focused into a thin beam in the focusing coil. Deflection coil moves the electron beam along the weld. Electron Beam is capable to weld work pieces with thickness from 0.0004” (0.01 mm) up to 6” (150 mm) of steel and up to 20” (500 mm) of aluminum. Electron Beam Welding may be used for joining any metals including metals, which are hardly weldable by other welding methods: refractory metals (tungsten, molybdenum, niobium) and chemically active metals (titanium, zirconium, beryllium). Electron Beam Welding is also able to join dissimilar metals. EBW is a high-energy density fusion process that is accomplished by bombarding the joint to be welded with an intense (strongly focused) beam of electrons that have been accelerated up to velocities 0.3–0.7 times the speed of light. The instantaneous conversion of the kinetic energy of these electrons into thermal energy as they impact and penetrate into the work piece on which they are impinging causes the weld-seam interface surfaces to melt and produces the weld-joint coalescence desired. EBW is used to weld any metal that can be arc welded; weld quality in most metals is equal to or superior to that produced by GTAW.

Electron beam welding is performed in a vacuum environment as the presence of gas can cause the beam to scatter. Due it being a vacuum process and because of the high voltages used, this welding method is heavily automated and computer controlled. As a result, specialised fixtures and CNC tables are used to move the work pieces inside the welding vacuum chamber.

This welding works on same principle of electron beam machining. This process uses kinetic energy of electrons to produce heat. This heat is further used to weld two welding plates. When a high jet of electrons strike at welding plates, its kinetic energy converts into heat energy. This heat energy is sufficient to fuse two metal plates together to form a weld joint.

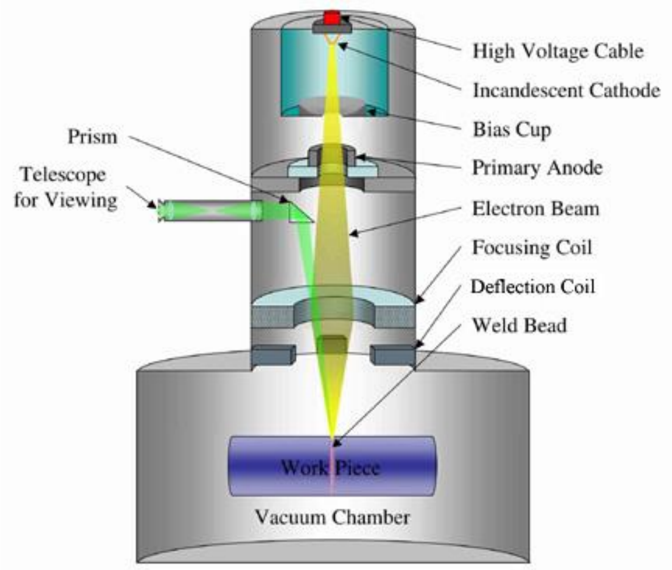

Figure 1- Schematic Diagram of Electron Beam Welding Process

II. EQUIPMENTS

Power Supply:

This process uses a power source to supply continuous beam of electrons for welding process. The voltage range of welding is about 5 – 30 kV for low voltage equipment's or for thin welding and 70 – 150 kV for high voltage equipment's or for thick welding.

Electron Gun:

It is heart of electron beam welding. It is a cathode tube (negative pole) which generates electrons, accelerate them and focus it on a spot. This gun is mostly made by tungsten or tantalum alloys. The cathode filament heated up to 2500 degree centigrade for continuous emission of electrons.

Anode:

Anode is a positive pole which is just after the electron gun. Its main function is to attract negative charge, (in this case electron) provide them a path and don't allow them to diverge from its path.

Magnetic Lenses:

There are a series of magnetic lenses which allows only convergent electrons to pass. They absorb all low energy and divergent electrons, and provide a high intense electron beam.

Electromagnetic lens and deflection coil:

Electromagnetic lens used to focus the electron beam on work piece and deflection coil deflect the beam at required weld area. These are last unit of EBW process.

Work holding device:

EBW uses CNC table for hold work piece which can move in all three direction. The welding plates are clamped on CNC table with the use of suitable fixtures.

Vacuum Chamber:

As we know, whole this process takes place in a vacuum chamber. Vacuum is created by mechanical or electric driven pump. The pressure ranges in vacuum chamber is about 0.1 to 10 Pa.

III. WORKING OF ELECTRON BEAM WELDING PROCESS

- First the electron gun, which is a cathode, produces electrons. These electrons move towards anode which is positive charged and placed right after electron gun.
- The anode accelerates the electrons and formsan electron jet which is further move towards magnetic lenses.
- The magnetic lenses are a series of lenses which are used to absorb low energy electrons and does not allow to divergent electron to passes through it. It provides a high intense electron jet.
- Now this electron beam passes through electromagnetic lens and defecting coil which are used to focus and deflect the electron beam at the required spot. This unit direct high velocity electron beam to the weld cavity where its kinetic energy converts into heat energy due to collision. This heat energy is used to create weld by fusion. This whole welding process carried out in a vacuum chamber otherwise the electrons collides with air particle in the way and loses its energy.

A TYPICAL ELECTRON BEAM WELDING PROCEDURE:

While every Electron Beam welding job is different, there is a base procedure we follow at EB Industries that allows us to maintain both weld quality and production rate.

- The parts to be assembled are thoroughly inspected and cleaned;
- Fixtures to hold the parts securely in place during the welding process are devised. We try to maximize the

number of parts that can be welded per vacuum cycle to maintain high production rates. If necessary, fixtures are custom made in our complete machine shop;

- Parts are loaded into their fixtures and the fixtures attached to the Electron Beam welder's CNC table. The CNC table is programmed to precisely move the parts into position under the electron beam during the welding process;
- The vacuum chamber is secured and the air pumped out of it to achieve the necessary partial or full vacuum required by the customer specification;
- If necessary, test welds are performed to check for proper beam alignment and focus, beam power, weld penetration and overall quality of the weld. Parameters are adjusted as needed, and continually monitored during all welding operations;
- If it is a production weld cycle, the welding operator initiates the CNC table programming and Electron Beam firing cycle. The parts are then Electron Beam welded;
- At the end of the welding cycle, the vacuum chamber is pumped down and the parts and fittings are removed from the welder;
- The parts are carefully removed from their fixtures and then subjected to a full quality control inspection.

The Electron Beam Welding process is conducted in High-Vacuum to prevent arcing. There are majorly three vacuum levels in Electron Beam Welding. They are as follows.

a) High-Vacuum welding – Here welding occurs in the same vacuum chamber as Beam Generation to produce the highest quality welds. These are extremely expensive mainly due tooperating and maintenance costs.
b) Medium-Vacuum welding – The idea of this welding is to reduce pump down time by weldingin a separate chamber.
c) Non-Vacuum welding – Welding is conducted at near atmospheric pressures. Here, the qualityof the weld is lowest.

CHARACTERISTICS OF ELECTRON BEAM WELDING:

The principle of the Electron Beam Welding is very similar to that of the Electron Beam Machining. The Electron Beam Machine is made up of three major components that may have separate vacuum chambers.

They are as follows.

- Beam Generation
- Beam Manipulation
- Forming and Working Chamber

Beam Generation

Here, the electrons are produced by passing current to the electron gun (Cathode) and heating it up to 2000℃ in a vacuum chamber. The electron gun operates at high voltages in the order of 60kV to 150$kV$to accelerate the electrons. The electrodes geometry here within the inter-electrode space defines the electron trajectory. In between the cathode and the anode is a modulating electrode known as the "Wehnelt cylinder", which regulates the electron flow. As the electrons pass through the anode, the electron beam converges and continues to move by inertia as it slowly diverges. In this manner the anode forms the electron jet by accelerating the electrons.

Beam Manipulation

The necessary power density is obtained by the electron beam for welding by passing it through the adjacent alignment and focusing system. The alignment and focusing system consist of a deflection coil and a stigmator coil. The deflection coil facilitates in maintaining the oscillating motion of the electron beam. The deflecting coils are then used to focus the electron beam at the required spot. This unit directs high velocity electron beam to the weld cavity where its kinetic energy converts into high energy due to collision. The stigmator coil helps rectify any aberrations of the magnetic lenses. The electron beam is then directed towards the magnetic lenses. These are a series of lenses that are used to absorb a series of electrons and also does not allow a divergent electron to pass through it.

Forming and Working Chamber

Each accelerated electron in an electron beam stores kinetic energy. While the kinetic energy stored in an individual electron is not very significant, in mass they can contribute to a very large amount of kinetic energy. Since electrons transfer their energy into a very thin layer of solid, the power density of the electron beam can be very high in the order of 10^4 to 10^7 W/mm^2.When the electron beam strikes the workpiece, the huge amount of kinetic energy developed within the accelerating electrons is converted into heat energy of the order of 10^5 to 10^7 W/mm^2. It has been identified that the heat energy produced from the kinetic energy of the fast-moving electrons is sufficient to melt the workpiece metals at the joint and fuse them.

Weld Parameters

The essential electron beam weld parameters include weld power as a combination of beam voltage and current, travel speed, working distance, vacuum level, focus coil current setting, and any unique beam oscillation requirements. The weld parameters are initially chosen based on operator experience and are further refined through a series of parametric weld studies using subsize mock parts, which allow the effects of the weld joint geometry on the weld shape and size to be determined.

Comparison Of Electron Beam Welding Process With Conventional Welding Process

- Compared with arc welding processes, EBW improves joint strength 15 percent to 25 percent.
- It has a narrow heat-affected zone (HAZ), which results in lighter-weight products.
- Geometric shapes and dimensions are highly stable, particularly when it is used as a finish operation.

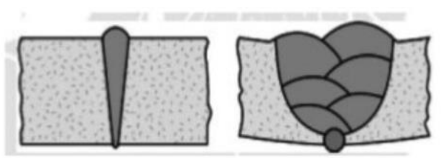

Figure 2 - Electron Beam Welding Process Vs Conventional Welding Process

IV. ADVANTAGES OF ELECTRON B EAM WELDING

Precise Control, Excellent Weld Depth

Weld penetration can be closely controlled — from a minuscule 0.001 inches to a depth of up to 2 inches.

Small Heat Affected Zone

Electron beam welding has a very high depth-to-width ratio. This allows for a deep and very narrow heat affected zone, which minimizes material shrinkage and distortion and allows welds in close proximity to heat sensitive components.

Strength

EB welds retain up to 95% of the strength of the base materials.

High Purity

Because electron beam welding takes place in a vacuum environment, impurities such as oxides and nitrides are eliminated and impurities in the materials are simply vaporized. This results in extremely clean welds perfect for joining a wide range of metal alloys.

Versatile

Electron Beam welding is excellent for joining refractory and dissimilar metals which are not weldable with the conventional welding process.

Production Capable

Our CNC controlled welders ensure precise control and repeatability at feed rates from 1 to 200 inches per minute.

No filler material used

Typically, no filler materials are used in the EB welding process. It is the parent material which is melted to create the join and thus the assembly.

V. DISADVANTAGES OF ELECTRON BEAM WELDING

Setup costs

The initial outlay for equipment is expensive. With these costs in mind, a company will need a large work-flow in order to justify the investment. It is usually more cost effective to outsource your EBW requirements unless you have a large volume throughput over a long period of time.

Equipment

Due to the complex technical equipment, expert operators are essential. If you are starting with a clean piece of paper, you will need to invest in professional training and employ experienced qualified welding engineers.

Size limitations

The size of the components to be welded is limited by the size of the vacuum chamber at your disposal.

X-Rays & Radiation

Safety standards are exceptionally strict as x-rays and radiation are both present during the welding process.

APPLICATIONS:

- It is used in aerospace industries and marine industries for structure work
- It is used to join titanium and its alloy.
- This type of welding is widely used to join gears, transmission system, turbo charger etc. in automobile industries.
- It is used to weld electronic connectors in electronic industries.
- This process is also used in nuclear reactors and in medical industries.

VI. LITERATURE REVIEW

Siddharth et al. [1],it defines the study of welding procedures and generation of weld for the Electron Beam welding process. Many research works have been done in the field of Electron Beam welding for optimization of parameter and welding.

Palmer et al. [2],itsummariesthe use of an advanced electron beam diagnostic tool, a means for quickly and easily transferring a set of welding parameters between electron beam welding machines at two widely separated locations has been demonstrated. The EMFC diagnostic tool is first used to characterize the beams produced by each welding machine over a range of focus settings at work distances spanning the height of the vacuum chamber on each welding machine.

Xiaomeng et al. [3],it defines that Electron beam welding (EBW) has many advantages as a space environment welding technology. EBW is suitable for vacuum operations. It can ensure the quality of aerospace material welding joints, high energy efficiency, and maximum penetration depth regardless of the material type and surface conditions. It has been tested successfully many times in actual space environments. The effects of the space environment on the welding technology are analyzed from the aspects of microgravity, vacuum conditions, and temperature differences in this article.

Yoshihiko et al. [4], conventional electron beam welding machine, an electron beam welding of bulk glassy plates has been achieved in the welding condition leading to the suppression of heat affected zone (HAZ). In order to obtain the cooling rate, which is sufficient for glass formation, the welding speed was controlled to be higher than 100 mm/s and the beam-radiated area should be limited to be smaller than 0.8mm in diameter.

Martin et al. [5],this paper presents the work performed within the frame of the International Thermonuclear Experimental Reactor (ITER). It deals with the computation of the mock-up manufacturing process of an element of the Vacuum Vessel (VV).ITER is an advanced fusion project which presents a lot of challenges at every technical levels especially on the manufacture of the VV which has strict tolerances (~ 10 mm) compared to the global dimensions of the structure (~ 10 m).

Shun Guo et al. [6], it determine the strengthening mechanism of adjacent welding, optical microscopy, SEM, EDS and XRD were applied for the analysis of microstructure and phase structure. Furthermore, tensile strength was also tested. The results show that due to the process of re melting and reverse solidification of intermetallic compounds(IMCs) layer, a less complex and thinner IMCs layer was formed and TiCu (553HV) with high embrittlement existing in the front of titanium substrate was changedintoTi2Cu(442HV).Performances of joints were optimized by these changes. An interpretation module was presented for the mechanism.

Sreekuttan et al [7], it defines different properties are essential for different parts and use of dissimilar metals joints gives possibilities of flexible design and products by using each material efficiently. EBW is one of the most widely used application in industries for joining dissimilar materials .The advantages of EBW welding is its high energy density, high depth to width ratio, low HAZ and result in very strong weld and low residual stress.

Raghawendra et al [8],In this letter, the residual stress (RS) induced by the high vacuum electron beam welding (EBW) of two high strength steels (HSS). X-ray diffraction (XRD) method has been used for the comparative analysis through the surface RS distributions in EB welded HSS, S960QL and S960M butt joint. Combination of power beam process with cutting edge technology of residual measurement for HSS characterize the novelty of this study.

Debin et al [9], it deals with the effects of welding parameters on the microstructure and mechanical properties of Ti/Cu/Ni joint welded by electron beam were investigated. High welding heat input increased the melting quantity of Ti60 titanium alloy and promoted the formation of Ti–Cu intermetallic compounds (IMC) such as Ti2Cu and Ti3Cu4, increasing the brittleness of the joints.

Guangjie et al [10],this paper investigates the WRS and deformation induced by LVEBW and metal active gas arc welding (MAG) in SUS310S thick-plate joint via numerical simulation and experiment. Based the simulation and experiment results, the WRS and deformation induced by the

LVEBW and MAG were compared quantitatively. Results show that the distribution of WRS induced by two methods are significantly different.

VII. CONCLUSION

From the above literature Review we conclude that,

- Electron beam welding has unique characteristics and advantages compared to existing welding technologies.
- The advantages of EBW are determined by the characteristics of the environment, including microgravity, vacuum conditions, and temperature variations.
- A high vacuum provides the natural environmental conditions for the application of EBW and favorable conditions for ensuring the quality of a weldment.
- EBW, characterized by a high energy efficiency and deep penetration, can not only achieve welding between metals, between metals and ceramics, even between metals and plastics, but also be used for melting, brazing, cutting, coating deposition, and other processes.
- EBW can act as a multi-functional tool for the installation and repair of space stations in the space environment.
- In summary, EBW has been verified to be feasible, reliable, and economical by various welding experiments. EBW is one of the most promising welding technologies.

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