White Paper – Advance Welding Technologies for Fabrication Industry

Technology Cluster Manager (TCM)

Technology Centre System Program (TCSP)

Office of DC MSME, Ministry of MSME

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Abbreviations

CNC	Computer Numeric Control
DC	Development Commissioner
EBW	Electron Beam Welding
EHS	Environmental Health and Safety
EV	Electric Vehicle
FDI	Foreign Direct Investment
FSW	Friction Stir Welding
FW	Friction Welding
GDP	Gross Domestic Production
GMAW	Gas Metal Arc Welding
HAZ	Heat Affected Zone
HLAW	Hybrid Laser Arc Welding
IFW	Inertia Friction Welding
LAMP	Laser-Assisted Metal and Plastic
LBW	Laser Beam Welding
LFW	Linear Friction Welding
MAG	Metal Active Gas
MIG	Metal Inert Gas
MPW	Magnetic Pulse Welding
MSME	Micro Small Medium Enterprises
PAW	Plasma Arc Welding
PET	Polyethylene Terephthalate
SWOT	Strength Weakness Opportunity Threats
TC	Technology Centres
TCM	Technology Cluster Manager
TCSP	Technology Centres Systems Program
TIG	Tungsten Inert Gas
TR	Tool Room
TWI	The Welding Institute

1. Introduction

1.1. Background

Technology Centre Systems Programme (TCSP) is a national programme undertaken by the Ministry of Micro, Small and Medium Enterprises with the assistance of the World Bank. The programme seeks to enhance the technological and skill base of MSMEs in certain manufacturing sectors to improve the competitiveness of MSMEs, via upgraded and new Technology Centres (TCs).

The objective of the programme is to enhance the productivity of selected MSME clusters by improving the access to manufacturing technology, establishing a strong focus in providing business & technical advisory services, and improving availability & employability of skilled workforce through TCs[1]. As part of the programme, KPMG has been appointed as the Technology Cluster Manager (TCM) to support TCs and undertake technology and cluster development activities.

The objective of TCM is to increase business opportunities for MSMEs through market linkages, enhance the competitiveness of the cluster business environment, increase the number of MSMEs utilizing the services of TCs, develop a financially self-sustainable business model for cluster related services provided by TCs, identify technologies (Industry 4.0) for the selected sectors for TCs, evaluate existing training programs & develop new training programs for rollout at TCs, conduct a gap analysis of TCs, strengthen the capabilities of TCs to provide technical advice to their clients, increase awareness amongst stakeholders on Environmental, Health, and Safety (EHS) requirements[2].

As part of the project, White Papers in different sectors are being prepared to help identify the future roadmap for the sector in general and the TCs in specific. This White Paper focuses on the advance welding technologies for the fabrication industry. Application of advance welding in the various sector increasing in the near future and key driver of the economy. Owing to its deep forward and backward linkages with several key segments of the industry, the advance welding industry has a strong multiplier effect on the economy[3].

1.2. Objective of White paper

This white paper is part of the engagement of KPMG with the Ministry of Medium, Small and Micro Enterprises (MSME) and aims to provide Advance welding sector-specific information such as leading global technologies, manufacturing techniques, the latest innovation in design, technology or manufacturing processes. This White Paper also highlights the degree of alignment of the current services of the TC with the market needs and recommend a future course of action for the TC to serve the sector in synergy with the ongoing trends. The TCs will contribute by providing inputs to MSMEs on manufacturing technology & business advisory in these areas. The paper further contains suggestions on the adoption of new technologies in the Advanced Welding Technologies by TCs and MSMEs in the cluster.

[1] DCMSME website, 25 May 2020
[2] DCMSME website, 25 May 2020
[3] Annual Report DHI 2018-19

2. Advance Welding Sector: Overview

Welding is the most common operation performed in the manufacturing methods and quality of joining is critical impacting and signifying the final quality of the assembly. Continuous efforts are put in to develop appropriate designs and joining processes as an essential part of the complete manufacturing process.

Automobile manufacturers are continuously on the lookout for innovative materials for improving efficiency, weight reduction and more importantly to meet regulatory green norms. Advanced fibre reinforced plastics and composites, in general, are the first approached materials for reducing the weight. However, welding of the dissimilar materials like magnesium, titanium, aluminium, stainless steel, and other high strength alloys pose challenges and latest welding techniques are to be adopted for welding metal to metal, plastic to plastic, plastic to metal and other bi-metallic material parts.

It is very important that most suitable welding method is to be carefully chosen to join such similar and dissimilar components. Materials to be welded and design of the joint are critical for the selected welding process to achieve good quality weld. Inspection of quality of joining is the next challenging task.

Different welding processes are used in the manufacturing of automobiles' bodies, structural work, tanks, and general mechanical repair work. Welding is also used in other industries like Power, Rail, Ship Building, Infrastructure, etc.

Electric Vehicles

Automotive engineers are striving to achieve light weight in their vehicle designs and use the non-lighter materials only when there is no other option and it is necessary. In the process of achieving the lighter designs, designers opt for various bi-metallic and dissimilar joints, like aluminium with copper etc. This light-weighting is the current trend in almost all the industry sectors.

But there are always challenges in the joining of bi-metallic or dissimilar metal combinations as materials having different alloying elements, different physical properties with weldability issues and some of the materials are taken as not possible to join using the conventional welding techniques.

Friction welding, which is one of the latest welding technologies, emanates as the most opted joining method. Friction welding is a solid-state welding without melting of the materials; it is considered as the most preferred welding technique for bi-metallic and is commonly used for welding materials in EVs. This solid-state welding is energy efficient technique, environmentally sustainable process and serves well in the light-weighting process.

2.1. Global Welding Market

The global welding market size was US$ 19.53 billion in 2019[4]; it is expected to reach US$ 27.22 billion in 2027 with a CAGR of 4.3% during the period.

[4] Fortune business insights: welding market 2020-2027

The welding industry has developed extensively in the last few years. This industry is driven by the advanced welding methods and equipment; and wide range of scope of applications of the joining processes. Scarcity of manpower is a global scenario and is the main influencing factor in implementation of automation using robots in almost all the manufacturing sectors. Moreover, implementation of the latest advanced welding techniques and associated processes like controlled joining, feedback systems with sensors is helping to enhance the productivity, flexibility for adoption and faster ROI.

The construction industry is growing at faster pace in the developing countries like China, India and other countries and the growth is consistent globally. The increasing demand is due to the increased activities in manufacturing industries, commercial and non-commercial construction activities. Moreover, the widespread growth in aerospace, automotive, shipbuilding and transport industries is ensuing high growth in the market.

Continuous growth of infrastructure facilities is going on throughout the world and in all the nations – China, India; Europe and Americas countries. Investments by the government are also growing in the infrastructure sector. Besides, enhancing and renovating activities in the infrastructure facilities are supporting the projected growth for the period. Mandatory regulatory compliances, light weighting, development of manufacturing processes, growing Electric Vehicles trend, latest research and developments in materials, sensors, fixtures, use of CNC supported operations in the welding processes, are facilitating high growth in the welding industry globally.

2.2. Indian Welding Market

In India[5], welding contribution in GDP is very significant and in various ways - like Fabrication industries, supplementary tools, manpower engagement, fabrication equipment and supporting industries. In India, the welding industries are using out-dated or not-up-to-date technology and mostly of conventional welding processes like gas welding, arc welding and others. However, use of robots, automation, technology and process improvements are rising significantly.

India has seen high foreign direct investment equity inflow in various manufacturing sectors of automobile outsourcing projects, process and power sectors, ship building and heavy equipment manufacturing industries. In India, many overseas companies have established their automotive manufacturing plants, which have seen a high demand and rise in the Indian welding market.

For a short period, economic crisis has affected, lowered the inflow of Foreign Direct Investment and in weakening the welding market. The Indian equipment manufacturers are facing a challenge of that significant welding tools are being imported. Another setback is that imports have increased considerably in the manufacturing sectors of Automobile, Shipbuilding, Heavy machinery and other industries.

Another factor affecting the industry is that electrode manufacturing industry is not an organized sector which is currently of about 50~55% of the welding market. The growth of electrode industry sector is getting severely affected due to the lack of standardised and rationalised specifications; resulting complicated product approvals and acceptance

[5] Overview of the Welding Industry in India: Challenges & Applications, CII, 26 Oct 2020

procedures. Welding equipment and consumables industries must improve their quality and must manufacture high quality products to become economical and gain edge in the domestic and global markets.

Welding finds its application in a variety of industries and sectors and below are the anticipated investments to show potential for welding applications:

- **Shipbuilding**: Shipbuilding industry contributes well to the Indian economy. Welding has high growth prospect in this industry. Opportunities are assessed because half of the current fleet of ships are of more than twenty years old and this presents scope for large opportunities for the growth in the shipbuilding and repair industries.
- **Railways:** It has very large network spanning more than 65,000 KMs making it as the 4th largest railway network in the world after US, China and Russia. It operates more than 19,000 passenger and freight trains per day. To increase investments, 100% FDI has been allowed.
- **Heavy Engineering:** Heavy Engineering sector has seen significant growth in the past few years as enhanced investments are driving the growth, as it has seen the FDIs of more than USD 3,000 million between the years 2000 and 2016.
- **Automotive:** India's average production rate of vehicles is more than twenty-four Million vehicles per year and in the world, it occupies the sixth position in automotive production. India is expected to enhance the production facilities and is expected to rise to 3rd position by 2026.
- **Construction:** India has a very good focus in developing this sector. Indian Government planned to develop hundred Smart Cities and five hundred AMRUT Cities. The estimated investment in urban infrastructural projects is of US$ 650 Billion. Total planned investment in infrastructure sector is of US$ one trillion.

2.3. Opportunities for Indian manufacturers

The 'Make in India' program is the huge thrust behind the changes in approach and attitude in the industries look-out, innovative ideas, going for new processes and investments in all the sectors of manufacturing[6] industries landscape. This is evident from manufacturers' intent and approach towards the improving the processes like to incorporation and use of dissimilar metals and materials in a greater number of components. This is seen more dominantly in sectors like automobile, where compliance to mandatory emission norms, improved efficiency and functionalities through reducing the weight and by other means, are the current trends and demands of the consumers.

Considering the current use of low-level technologies in India, advantage can be taken from it by jumping directly to the latest advanced welding technologies leaving the in between technology stages. The important factor to be noted is that arc welding will remain as the most commonly and excessively used welding process, and it is going to remain like that in the near future also; and this is true not only for India but across the globe. The arc welding is of about 35% of the global welding market and welding is being done with some form of conventional arc welding from manual to automated processes.

2.4. Joining of parts and Assembly Operations

[6] EMERGING TRENDS IN THE INDIAN WELDING SECTOR - CHRIS WISEMAN

For producing any assembly product, welding is the most used process in the manufacturing industries. The assembling methods mainly considered are mechanical assembly and metallurgical welding. Mechanical assembly mainly comprises of fastening with bolts, riveting operation etc. All these processes involve mechanical methods for joining the parts and at no stage metallurgical properties are altered. Whereas Metallurgical welding can be considered as the joining operation where heating is applied to plasticising temperatures are above, applying forces for joining, and adding the molten materials for joining. There are other methods of joining where chemicals are used for bonding.

All the joining methods have their own benefits and drawbacks. Selecting a suitable and appropriate process considering the work materials and working conditions is the key to achieve the precise assembly.

All these assembly processes are essential in the manufacturing industries, but few key factors like, process efficiency, automation and productivity, weight considerations, easy and safe preparations of workpieces, strength etc. may lead to consider welding as the first choice of joining methods. Inspection and qualifying the joint is the next challenge.

It is very important that a proper welding method is to be chosen for joining the parts; the selected process may impact immediately in commercials and/or may be functionally in the long run. Quality of the welding largely depends on the materials to be joined and the joint design as per the selected joining method.

Modern welding technologies started getting popularity just before the end of the 19^{th} century. It is perceived as that Latest Welding technologies are characterised by less local heat source intensity, less heat affected zone, quality welding, productivity and welding dissimilar materials. The following Latest Welding technologies are proposed for discussion here.

1) Laser Beam Welding
2) Electron Beam Welding
3) Friction Welding
4) Ultrasonic Welding

Conventional fusion joining methods like Tungsten arc welding, plasma arc welding, MIG and other welding’s are not considered within the scope for review here.

3. Laser Beam Welding

Laser Beam welding is a method of joining the work pieces using the laser beam as a heating source. The laser beam delivers a focussed high density of energy heat source resulting in narrow affected heat zones and deep welds. Laser welding is a quality, precision, and high-speed welding and automation can be implemented in the process.

3.1. Laser welding process

Power source delivers the energy to the exciting medium so that the electrons are raised to higher energy levels. The energised electrons generate spontaneous emission of the photons and stimulated emission. The resonating mirrors provide the higher amplified emission and direction. Optical lenses and reflectors guide and focus the beam on to the work piece surface which is to be welded. The conversion of the laser beam energy into heat energy on the work-piece surface provides the heating resource.

The focussed heat melts the material on the surface. The laser beam density levels are controlled such that the temperatures on the work piece do not reach and make the material to vaporise. Laser has an advantage in working with high thermal conductivity materials. One of the concerns that beam may get reflected from the surface of the work-piece without than providing the heat source did not hold good as it is found that after the surface reaching near to the melting point, the surface does not have any effect.

Laser Beam Welding and Electron Beam Welding have the same characteristics except negligible differences. The focussed energy levels of both the beams are almost the same. The difference is that energy density of the electron beam is slightly greater. Some of the controlling parameters of Laser welding are – Power of the laser, speed of operation, point of focus, frequency of the laser, flow rate of shielding gas etc. For achieving high quality in the joints, setting up and controlling the operation parameters in optimised condition is crucial. Many weld defects like oxidation inclusions, porosity, change in the alloy materials, crack development during solidification etc will be induced, if the operating parameters are not set correctly.

3.1.1. Laser Welding Modes

Laser welding process is carried out with two working modes, in general. Conduction welding is the first mode, where heat distribution into the material is by conduction. The second process is keyhole or deep penetration welding, in which the laser is concentrated to attain a very high-heat density, resulting in creation of a hole with molten metal pool absorbing the laser beam heat source. The produced vapour effects in the creation of plasma plume. Welding's from the first conduction are with less depth penetration and are of dish shaped. Welding from the second method, in keyhole mode are characterised by a moderate fusion zone (FZ) and small heat affected zone (HAZ).

3.1.2. Laser Spot Diameter

Predominant Application Areas of Laser Beam Welding

- Gas Laser (CO2) Welding
- Solid-state laser (Nd:YAG type, ruby lasers etc.) Welding
- Fibre Laser Welding
- Diode/Semiconductor laser welding

Generally, a selected laser beam of a good beam quality and dia. of 0.4mm can produce welding combinations like (a) high speeds with a specific deep welding(b) increased deep welding for a specific speed. The types of lasers used for laser welding can be generally divided into gas lasers or solid-state lasers.

3.2. Gas laser (CO2 and other Nitrogen, Helium gases)

Gas Lasers use carbon dioxide (CO_2) which is very popular with gas lasers or other gases like Nitrogen, Helium. These Gas lasers use power source of lower current, higher voltage to stimulate the gases of lasing medium. Gas lasers can be operated in a pulse mode or continuous mode. High-power CO_2 gas laser machines of power up to 50kW fare developed. These lasers have the higher welding capacity of more depth and higher speed operations. The CO_2 laser is one of the first gas lasers developed.

3.3. Solid-state laser (Nd:YAG type and ruby lasers) Welding

Solid-state lasers use a solid as lasing medium, rather than a gas as in gas lasers. A crystalline or glass base material to which common dopants, rare earth elements like chromium, neodymium, thulium or ytterbium are added - is used as the medium of solid-state laser.

A solid-state laser uses ore such as yttrium, aluminium, and garnet (YAG) or yttrium vanadate crystal (YVO4) as the laser medium. Large laser output is possible even with a small resonator as solid-state lasers have a large laser output. They can operate in both pulse mode and in continuous mode. Operation in Pulse mode produces joints same as that of spot welding but with better deep welds.

3.4. Fiber Laser Welding

Fibre laser welding using optical fibres for oscillation, as well as semiconductor lasers and disk lasers developed from YAG lasers have increased in popularity. Optic fibre doped with rare earth materials like ytterbium, erbium, dysprosium, neodymium, etc. are used as the active gain mediums in the Fibre laser. These are connected to fibre amplifiers, and these amplifiers produce light amplification without lasing. A Fibre laser is a type of solid-state laser that using an optical fibre as the medium. The amplification fibre is an optical fibre called a "double-clad fibre". Output side is also provided with a low-reflectance mirror. Fibre laser welding continues to grow as a preferred welding process with improvements in weld quality, reliability and performance.

3.5. Diode/Semiconductor laser welding

In this type of diode laser process, a laser beam is produced, when current is passed through a semiconductor, which is used as the heating source for joining. These devices are compact when compared with other laser beam techniques as the lamps are not used as the source for excitation purpose.

In semiconductor laser, by passing current through a semiconductor, an oscillated laser beam is generated. The quality laser beam produced in the process is of higher conversion efficiency. Oscillated high energy laser beam is comparable to the electron beam.

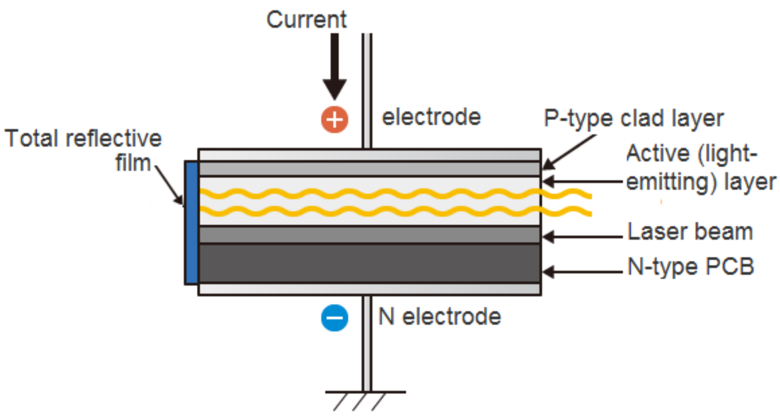

Figure 1: Semiconductor Laser

3.6. Hybrid laser welding

The hybrid laser arc welding (HLAW)[7] – currently it is being used widely, especially in ship-building industry and was announced by Prof. W. M. Steen in the late 1970s. Hybrid laser arc welding process, as the name indicates is a laser beam welding used in combination with one of the other conventional welding techniques. The conventional welding techniques which can be used in combination with laser beam, are metal active gas (MAG), metal inert gas, tungsten inert gas and plasma. The laser beam provides the primary heat source and the combined compatible second process provides secondary heating source in the hybrid welding technology.

Advantages of Hybrid welding are - Fast welding speeds with strong gap resistance, deep penetration, and low distortion.

3.7. Typical Output and Conversion Efficiencies

Laser type		Output	Max Conversion Efficiency (%)
Gas	CO_2	Continuous-20 KW Pulse - 10 MW	20
Solid state	YAG Laser	Continuous-400 W Pulse - 10 MW	3
Semiconductor	Diode Laser	Continuous-100 MW Pulse-10W	100

Table 1: Laser types, output and conversion efficiencies

3.8. Metals which can be welded with Laser Welding

The laser beam can be used to weld:

- Carbon Steel
- Aluminium
- Titanium
- Low alloy steel
- stainless steel
- Nickel
- Platinum
- Molybdenum
- Kovar (nickel–cobalt ferrous alloy)

[7] Source: Advanced welding technologies used in aerospace industry –Aliaksandr Zavadski

3.9. Benefits of welding with laser technology

- **Precision Welding:** Laser welding process gives a more accurate and controlled environment. It can be used to weld small and thin parts, without affecting the original parts and with no distortion in the original parts.
- **Dissimilar and complicated joints:** Laser welding technology can be used to weld all type of materials especially dissimilar materials. It can also be used well where the use of conventional processes poses difficulties.
- **Process with Minimum heat input:** Distortion of the components is minimum because Laser welding technology is a focussed with minimum heat input method. This minimised distortion in the process makes it as the most preferred welding technique.
- **Reliable and repeatable Process:** Welding operations can be carried out at higher production rates. Lasers Beam welding is the most opted welding technique of Manufacturers as it produces reliable and quality welds.
- **Strong welds:** Laser beam technique is used to achieve strong welds. Filler material is not a must. Laser welding gives excellent quality and clean operation. Due to this fact, that laser welding highly preferred especially in the medical industry in which safety of the equipment is of supreme importance.

3.10. Limitations

Controlling the concentration of the beam permits faster welding speeds, however, in the process input of the heat is reduced. The other limitation factor is the requirement of close tolerances of the gap between the parts to be welded demanding more accurate edge preparation work.

3.11. Laser Beam Welding Applications

- **Aluminium alloy fuselage:** The conventional method of manufacturing of fuselage using the aluminium alloy material in an aircraft was based on assembly of stringer and skin panels using the riveting process which is less efficient and high cost. A trend has been developed in Aircraft industry; to substitute the riveting process with Double-clad fibre LBW. This is now a well-established method for aircraft manufacturing with the benefits of reduced weight and cost.

- **Automotive**: The process is suits well in the automotive industry where capability of mass production is the main requirement. As this process offers the benefits like more flexible operation with good adoptability, increased production rates with quality and strong welds with less energy consumption resulting in large savings in the power costs. This process suitable in automobile industry where mostly metal sheets of thickness up to approximately 5mm are required to be welded and which can easily be achieved with Laser beam welding technique. Another preferred automotive application is for welding the roof panel with side panels. The requirement is watertight welding with less distortion which can be achieved.

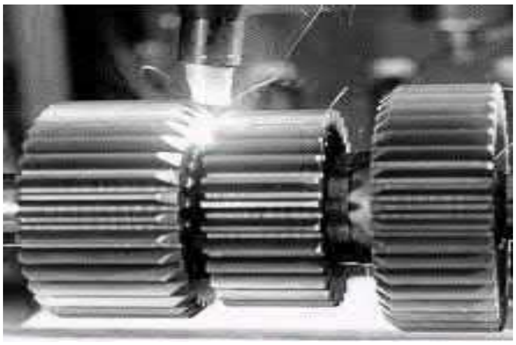

Figure 2: CO2 Laser welding of Gear Component

Figure 3: Automation with Laser Welding

- **Ship Building**: Hybrid Laser welding is getting more and more popular usage in Ship Building industry – due to inherent process requirements in the industry. Typical welds can be of 30 m long and 15 mm thick plates. However, the limitation with the methods in this industry is that the gaps are bigger between the plates to be joined and the normal laser beam welding cannot fill such bigger gaps. To overcome this issue, hybrid welding is preferred to bridge gaps where LBW is mostly combined with the MIG technique for the secondary heat source.

4. Electron Beam Welding (EBW)

Electron Beam Welding technology is a fusion based joining of materials using the heat generated from the beam of electrons with high velocity. Electrons produced from a cathode gun are guided through magnetic fields to higher velocities. This beam of electrons possesses high kinetic energy and is converted to thermal energy when they are focussed on to the work-piece materials. The presence of atmosphere or any shielding gas may affect the beam in scattering; hence, Electron Beam Welding is carried out in vacuum chambers. Moreover, EBW process is highly automated using the CNC controls and fixtures due to the high voltages involved and operation is being performed in vacuum[8] chamber.

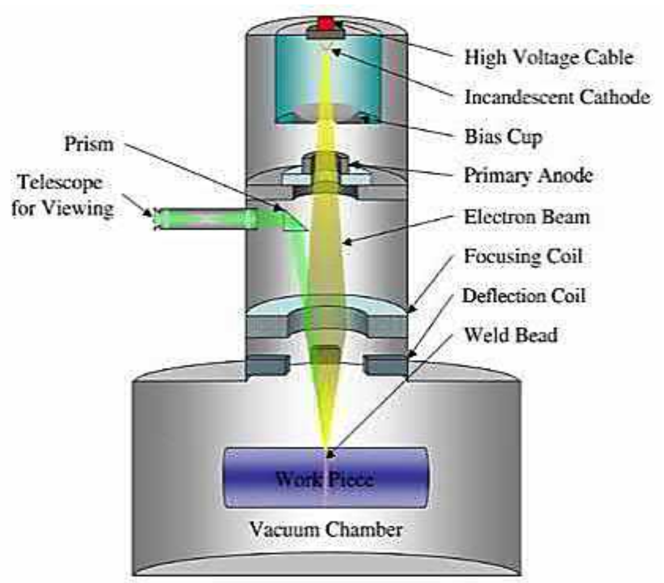

Figure 4: Electron Beam Welding Working

4.1. EBW Process

- Electrons are emitted from a heated cathode in vacuum. Controlling the voltage, higher velocities are imparted to these electrons and are focussed through magnetic fields created by coils.
- High heat energy is produced when the accelerated electrons with high kinetic energy are stuck on the workpiece. Heat applied at weld is very less, resulting very smaller distortions in the process.
- Penetration of welding can be controlled by adjusting the beam output. This makes the process applicable for wider requirements of not only materials but also high range of thicknesses like less than a millimetre to more than 300 mm based on the materials.
- As Electron beam welding is performed in vacuum, the range of materials that can be welded widens including chemically active materials like titanium. The temperature can be attained is very high makes the process suitable for welding materials with higher melting temperatures like Tungsten.

The EBW can be used for continuous welds or for spot welding. In general, filler is not a must, unless based on the weld ability of the materials, filler material is demanded. Edge preparation is not a must.

4.2. Types of EBW Machines

Electron beam welding machines can be categorised based on the voltage capacity for beam acceleration, the vacuum and chamber area, and the beam gun mounting type. Mainly these are the factors deciding the equipment size and capacity sizes of welding operations. In general, thickness ranges are very wide, and which can be welded are steels 0.1 - 250 mm, and that of aluminium is 0.1 - 500 mm. Electron beam welding machines can also be used

8 Mech for study report on Electron Beam Welding:2017

without full pledged vacuum. More research is going on for portable and capable of performing the operation in the open atmosphere.

The beam gun can be placed in the chamber or outside to it. If the gun is movable, the welding location is positioned by the movement of the beam gun. The electron beam gun is fitted, in the equipment, to a robot which can be controlled in five axes simultaneously - 3 linear axes and 2 rotation axes. This CNC controlling makes the equipment capable of 3-dimensional welding. Some of the manufactures are claiming the equipment with vacuum area of more than 10 m^3. Quality is ensured through low power x ray scanner capable of scanning all the welds and a sensor detecting and giving the feedback of the welds achieved.

4.3. Advantages of EBW

Electron beam welding can be used for a wide range of thicknesses and it is possible to weld even higher thickness materials for Aluminium. EBW technique is used for welding different types of steels and normally hard-to-weld materials like refractory materials – molybdenum, tungsten etc. and materials like titanium, beryllium, zirconium etc. which are chemically active. Electron beam welding can also be used for producing joints between different metals and various non-ferrous metals, plastics and composites.

- The electron beam welding technique is highly sustainable and repeatable as high automation is used in the process and is a precision welding technology.
- EBW welding process produces very strong welds which are used in high-end-applications across all the sectors. creates strong joints that can be used for a number of high-end applications across a wide range of industries.
- The Electron beam welding technique results a very narrow heat affected zone, which minimizes distortion and material shrinkage.
- The process is carried out in atmosphere free environment – in vacuum, there is no or less scope for any contaminations to be left out in the welds. Other impurities like Oxides and others are vaporized at the temperatures and eliminated in the process.
- This is a well-controlled and automated process, very good choice for welding dissimilar materials including refractory materials.

Electronic Beam Welding-Use

- Joining different grades of steel
- Refractory metals (tungsten, molybdenum, niobium)
- Chemically active metals (titanium, zirconium, beryllium)
- Different metals
- Plastics and composites

4.4. Limitations of EBW

The use of vacuum chambers in the process limits the sizes to that of the chamber. Similar to the laser beam welding, bridging the gaps in weld is not possible and closer tolerances are required between the surfaces to be welded. The most important limitation of the process impacting its usage is the high initial investment costs involved.

Even small magnetic fields can deflect the electron beam easily, hence, welding of such materials which may retain magnetism present challenges.

4.5. Electron Beam Welding Applications

- **Aerospace Components:** EBW is being used extensively in Aerospace industry for the manufacturing of engine parts. It is extensively used in welding of blades of the stator. This process is capable of meeting the demand of maintaining control on the close dimensions due to the changing profiles in sections of the blades.

- **Repairs:** Electron Beam welding is widely used in Automotive industry, another good application of it is in the engine manufacturing especially for repairing and refurbishing of the gas turbine parts damaged due to and in the working conditions. The EBW technique is the choice for welding and working on the blades of fan of titanium material as the process is being carried out in vacuum. The method of repairing the blade of the fan involves first removing the damaged area on the blade and then a patch is added by welding and repaired as shown in below in Figure 5.

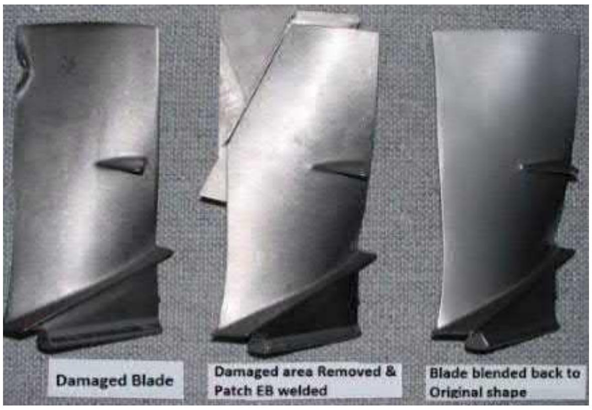

Figure 5: Fan Blade Repair with EBW

Figure 6: Compressor Rotor with EBW

In the manufacturing of the compressor rotors, the EBW is efficiently used in the welding of machined discs to build-up a multidisc rotor, as shown in above Figure 6.

- **Automotive Components:** The EBW is used for welding gear/synchronizers, clutch-shafts planetary gear and transmission parts and related parts, as shown in Figure 7.

Figure 7: Automotive components manufactured with EBW

4.6. Laser Beam Welding Vs. Electron Beam Welding

A common question often heard in the precision welding requirements is – what is preferred welding EBW or LBW? The best process to choose generally depends on the details of the application. LBW is normally the first process to check for the application. LBW is more economical than EBW operation. However, if the required welding depth is of higher, EBW is the optimal process, as with EBW higher depths of welding can be achieved with quality. EBW is the first check and the best welding technique for the welding of materials of titanium and similar, but EBW is with the limitation of the sizes that can be placed in vacuum chamber.

LBW is very effective technique with lower costs, whereas EBW results better quality joining. Another factor to be considered is that EBW productivity rate is high and ROI can be achieved faster.

Electron Beam Welding vs. Laser Beam Welding			
Parameter	Electron Beam Welding	Laser Welding	
		CO_2 (carbon dioxide) Laser	YAG Laser
Heating device	High voltage generator + electron gun	Optical resonator+ medium of gas -CO_2	Optical resonator+ medium of YAG material
Commercial equipment Output	3.0kW-100kW	0.5kW-45.0kW	0.1kW-6.0kW
Thickness	Approximately 150 mm	Approximately 30mm	Approximately 10mm
Efficiency of the energy	Almost 100%	Approximately 80% -loss in the surface's reflection	surface absorption little more than CO_2
Welding atmosphere	in vacuum	Open air+ Inert shielding gas	Open air+ Inert shielding gas
Materials which can be welded	Metals (Materials with less vapor pressure like Zn and Mg)	Metals and nonmetals	Metals and nonmetals

Table 2: Electron Beam Welding vs. Laser Beam Welding

5. Friction Welding

Friction welding is a process generating the frictional heat with the relative movement between two components and joining the parts under pressure. Friction creates intense heat that rapidly fuses them together. Dissimilar and both ferrous alloys and non-ferrous alloys are welded using the Friction Welding methods. Friction Welding is achieved at sub-melting temperatures of materials; hence, materials of dissimilar melting temperatures can be welded.

In some of the welding requirements especially of dissimilar materials, the joint with conventional technologies may not result desired mechanical properties of the joint. With those materials, friction welding is the only choice. Factors like no use of filler metal, no shielding and can be used to join dissimilar metals made this technique widely used for commercial process.

Friction Welding Applications

- Solid State Welding
- No use of Filler material or flux
- No requirement of shielding gases,
- High quality Welding
- Dissimilar metals can be joined
- Automation is possible for mass production

Depending on the types methods used for friction and heat generated, the welding can be classified as:

- Friction Stir Welding (FSW)
- Linear Friction Welding (LFW)
- Inertia Friction Welding (IFW)

5.1. Friction Stir Welding (FSW)

Friction stir welding is a joining method of materials using the heat produced under a rotating tool which is not consumable. When the tool is rotated in relation to the work piece touching on their surfaces, heat is produced by friction between the work piece and the tool. Due to the generated heat, the work-piece material becomes soft before reaching the melting temperature and providing strong bonding in that soft state.

Advantages and Applications of FSW:

- Friction stir welding is commonly used and the most important joining process in aerospace industry especially for structures, as it accomplishes quality joints for all aluminium alloys which cannot be welded with conventional welding techniques.

Friction Stir Welding range

- Aluminium alloys – thicknesses of 1.0 mm to more than 70 mm including Aluminium and Lithium alloys also
- Welding of magnesium, titanium, copper, zinc and refractory materials
- Dissimilar: Cu– Al; Al– Mg; Al – Al alloys
- Environmentally friendly and efficient process

- Dissimilar alloys can also be welded with FSW technique. The results are also positive in the joining of dissimilar materials with same and different **melting** temperatures as Al– Mg,

Cu– Al, Al– Al alloys Mg– Mg alloys. FSW is capable of welding of magnesium, titanium, copper, zinc and other refractory materials.
- No shielding gas or filler material are required
- FSW is environmentally friendly and efficient process
- Railway components: FSW is being used in the rail manufacturing industry for more than decade now.

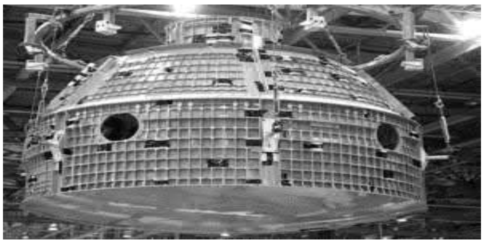

Figure 8: Space Craft module – use with FSW

5.2. Linear Friction Welding Process

Linear friction welding (LFW) is achieved by the linear oscillations of a part relative to the other, and the large applied force results in high friction and heat produced between the surfaces of the parts to be welded.

Process:

Once the interfacing surfaces reach to a plasticizing temperature, the oscillations are stopped with the parts in the aligned position. At this stage, the increased pressure fuses the bonding.

Advantages:

- In the joining process the interface temperatures are maintained less than the melting temperatures of the materials leads to reduction of weld defects such as solidification cracking, voids, pores, inclusions, distortions etc. which are the general issues in conventional welding.
- The process is highly efficient and environmentally friendly.
- High integrity weld and recrystallized structure may result maintaining the same or increase in the tensile strength.
- Full automation is possible with Linear Friction Welding and it is sustainable process.

Applications:

- LFW process can create joints in Titanium and Aluminium alloys, dissimilar materials etc.
- Good mechanical properties are seen in Stainless Steels, with the properties similar or superior to original materials.
- The LFW technique is well used in the welding of Titanium alloy blades and disk which is known in the industry as blisks. In a conventional turbine manufacturing, the blades are attached with interlocking mechanism increasing the weight considerably. With the LFW technology, a single assembly is manufactured by welding the blades to hub, eliminating the interlocking method with considerable reduction in the weight.

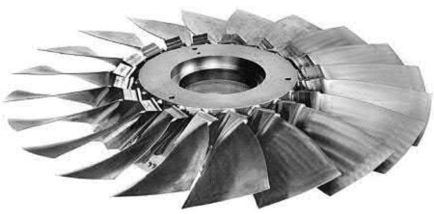

Figure 9: Linear Friction Welded blisk assembly

5.3. Inertia friction welding

In Inertia friction welding (IFW), materials are joined by using the heat produced by the friction created by rotating one part with respect to another, and pressure is applied to fuse the workpieces together in plasticized stage.

Process:

One part is fixed in a rotating chuck, and the second part is fixed in a chuck which is not rotating. The parts are moved closer and axial force applied causes the plasticised materials to join. Many similar and dissimilar material combinations can be achieved under proper conditions.

Advantages and Limitations:

In general, all the advantages of solid-state process hold good - such as filler material is not required, no work piece preparation and no shielding, repeatable process etc. Major limitations of IFW is high capital investment, flash machining, limited to round shapes except few.

IFW Application:

- The use of IFW is increasing steadily in all the industry sectors especially in aerospace industry due to its inherent quality of the joints.
- In joining nickel based super alloys, titanium alloys and steel.
- Automotive: Some of the components manufactured using the Friction Welding are:
  - Stabilizer bars
  - Engine valves
  - Pistons
  - Drive shafts
  - Transmission gears
  - Turbochargers
  - Suspension Components
  - Bumper shocks
  - Steering Components
  - Water Pumps
  - Axles
  - Camshafts
  - U-joints
  - Brake Callipers

5.4. Ultrasonic Welding

In Ultrasonic Welding, high frequency ultrasonic movements are used to produce heat and to join the parts under proper pressure in fraction of a minute. This Ultrasonic joining is characterized by very less heat input; placing the workpieces between a joining tool and anvil; and applying the force.

Process:

The technique of Ultrasonic welding is applied for both metals and plastics, main difference being the ultrasonic oscillation direction. Process description given below is mostly for plastics but applies for metals also.

For joining of plastics in ultrasonic welding, ultrasonic oscillation direction must be at right angle-90° with the welding surface. The ultrasonic vibration is of tens of thousands of waves per second and these oscillations produce high temperatures. In the case of Plastics, they are very poor heat transmitters, hence, can't disperse the heat quickly and prior to plastic is changed to plasticity state. In that state as the axial force is applied and the two work-pieces merge together and the resulting joint is like as if they are a single component.

The two parts which are to be welded together are placed in a fixture- a supporting frame; and one part is placed on the top of another plate.

Advantages:

- The ultrasonic welding is fast at high production rates and high welding strength
- Better quality joints than traditional processes
- Lower production costs

Disadvantages:

- If the thicknesses of the components increase, the requirement of the power increases tremendously like in geometric series which may increase the manufacturing costs.
- The joining shapes and size ranges may create limitations.
- high-frequency sound, may cause issues with the working personnel, but can be solved by enclosing the ultrasonic welding machine and/or using ear protection

Application:

- Ultrasonic joining is applicable for almost all the thermoplastics.
- Ultrasonic joining is the most suitable technology for joining metal sheet to plastics/fibre
- Ultrasonic joining is widely applicable in almost all the industries for welding the plastics. Applications are very common in the industries like Automobile, Electronics, Medical equipment, Food and Packing.
- Ultrasonic welding is used very effectively for joining thin sheets of nickel, copper, and aluminium foils and meshes.

5.5. Submerged Arc Welding (SAW)

The submerged arc welding (SAW) is a fusion type process using the heat created during an electric arc between continuous feeding electrode wire and workpiece.
The arc is submerged under a layer of flux on the materials to be welded. The flux shields the operation and the joining is sheltered protecting the oxidization from the atmospheric gases. It also decreases the splatters and any ultraviolet rays emitted during the operation. This is generally an automated process.

The important components of Submerged Arc Welding are:

- Power equipment
- Electrode feeding
- Granulated Flux
- Electrode housing

Process:

Power source is required - both DC and AC can be used. The consumable electrode is fed continuously through Electrode Holder, a non-conductor device. When electrode is brought down to the workpiece, spark is created between them and at the same time granular flux is also provided. The Granular flux also helps in reducing the excess heating of the workpieces.

Submerged arc can be used with different types of currents:
- **DC - Continuous current with positive electrode (+)**: results in good weld penetration;
- **DC - Continuous current with negative electrode DC (-)**: results in good welding rate;

- **Alternating current (AC):** results a balance between the other two methods of the DC (+) and the DC (-). We obtain a better weld penetration of the DC (-) and a better weld rates of the DC (+).

SAW welding method produces a very strong and good quality welds with good production rates. Submerged arc welding is generally used for the fabrication of large workpieces.

Key benefits and Advantages:

- High welding rates
- Quality and strong welds with ductility and impact resistance
- Production rates are very good in joining of materials of thin sheets
- Good welding depths
- The arc in the process is protected and not exposed to atmosphere
- Almost no or little surface edge preparations

Disadvantages are:

- Post-weld operations required like removal of slag
- May cause health issues due to flux and slag

Applications:

Materials that are generally welded are:
- Carbon steels- for structures and pressure vessels equipment
- Low alloy steels
- Stainless steels
- Wind turbine structural
- Piping etc.

The Submerged Arc Welding is widely used in process and construction industries to weld pressure vessel equipment and other equipment like boilers etc.

It is also suitable for heavy welding for structural frames, piping, heavy excavator machines and tools, shipbuilding, railways and construction.

5.6. Thermit Welding

This joining process name is based on the word “thermite”, a name for a chemical reaction of metal oxides and reducing agents. Thermit is chemical joining process using the heat source produced exothermically. In the process, Thermit, a mixture of metal oxide: Aluminium powder-1 portion and reducing agent: iron oxide 3 portions is burnt.

As a result of the chemical reaction, temperatures of 2500-3000°C can be achieved, however in order to ignite the reaction, Thermit mixture need to be pre heated to approximately 1200°C-1300°C.

The general reaction can be:

Metal Oxide + Aluminium → Aluminium Oxide + Metal + Heat

An example is: $8Al+3Fe_3O_4 \rightarrow 9Fe+4Al_2O_3$

As shows in the above chemical equation Aluminium readily mixes with FerricOxide and Iron and Aluminiumoxide are formed. Pure iron settles down below the Aluminiumoxide as its higher density.

Thermit Welding Process:

Thermit joining process is like a cast process; in this process heat from the exothermic reaction melts the metal and the melted metal is discharged into the sand or suitable cavity prepared nearby the weld. The steps are as follows:

- Ends of the parts to be connected are suitably cleaned and made ready for joining.
- Wax is filled in the joint, and other areas where exactly weld material is required -Wax forms like an expendable pattern in casting process.
- A box is placed around the solidified wax, appropriate sand is rammed in the box, required sprue pins, pouring basin and risers are placed; and vents are also provided.
- At the bottom, appropriate path for running down of the melted wax is also given.
- A strong container made suitable ceramic or metal is taken for mixing the Thermit – the container should be strong enough to take the high pressure at elevated temperatures throughout the exothermic chemical reaction.
- On the top of the Thermit, igniting material – may be of barium peroxide or magnesium -is placed and ignited using heated metal or appropriately lighted piece like magnesium.
- In less than a half minutes time, the exothermic reaction takes place and melted iron is guided to flow into the cast prepared.
- Joining is completed with the workpieces fusing together taking the heat from the molten material.
- The welding is permitted to come down to the ambient temperatures slowly.
- For welding various component materials like chromium, copper, etc., various types Thermit material mixtures can be selected.

Advantages of Thermit Welding:

- Thermit welding can be used for welding similar or dissimilar metals.
- This process is cost effective with no power supply required makes it more adoptable in the field sites.

Limitations:

- Thermit welding is basically used for heavy sections and not for mass production.
- This may not be suitable for thin and lighter components.

Applications:

- Thermit joining is widely used in joining rails of railway tracks and thick sections.
- Being used for long time in the welding largely thick plates.
- Large castings are mostly repaired using the Thermit welding.
- Thermit welding is the widely approved method for welding the copper cables.

5.7. Welding of Metal, Non-metal and Dissimilar materials

Quality joining between metals and non-metals makes extensive use of metal in various sectors. The welding of dissimilar materials like metals with non-metals gives out very useful and exclusive combination of material properties for the joined assemblies. The combination of properties can be like, giving as an example, is that by selecting proper combination of materials good thermal conductivity property at higher temperature combining with the property of good resistance at high temperature can be achieved. The joining of copper and ceramics like Al_2O_3 achieves good thermal conductivity in the produced assembly, and the assembly will also have the properties like high electrical resistance and good mechanical strength.

However, there are challenges in welding dissimilar components and often is difficult to weld. The behaviour of dissimilar welding, in general, is not anticipated to full extent, especially when heating methods are used. Welding of bi-metallic and non-metallic materials have become most researched subject and some of them are being used in manufacturing industries effectively. In this context, ceramic-metal composites are playing an important role.

Another method of joining of metal and non-metallic is generally done with high viscose glue water inlay or with non-metal (such as: aluminium oxide ceramics) metallize (plating) process, after that carry out them welded. Based on the type of two materials to be joined, brazing/soldering techniques specific to those materials are developed. Brazing fillers are prepared, with the combination of different alloys of nickel, copper silver, tin, titanium etc. in different proportions based on the base materials to be joined.

6. Use of Latest welding technologies

The latest welding technologies like, Laser Welding, Friction Welding, Ultrasonic welding are being used for the welding of materials of metals, non-metals and are more reliable and easier than before, especially laser beam technology seems more attractive in welding of materials of non-metallic and composites.

Laser beam welding parameters can be varied and set in such way that joints of various types of dissimilar materials can be achieved, with substantial benefits of – high quality weld, high productivity etc. in the joining processes. Dissimilar materials like aluminium to steel, aluminium to magnesium, aluminium to copper etc joints have been achieved very effectively with LBW.

6.1. Explosive Welding Technique

The explosive welding technology is being used widely in clad requirement of joining low cost sheets/plates (mostly of carbon steel) to costly materials with resistance to corrosion (e.g., nickel alloys, stainless steels, etc.). These clad plates are generally used in the process and chemical industries for tubes for heat exchangers.

The explosive joining is produced by the tremendous impact forces generated during the explosion of a charge (different types of available chemical explosives are used) and the plates are impacted one against the other. The impact should produce very high pressures when the parts are contacted with each other, such that the resultant pressure should be more than the yield strength of the both the materials so that plasticity is achieved at the surfaces of contact. The plasticised soft metal permits producing solid state bonding between the two parts.

As the binding is of solid state, the process can join materials of varied melting temperatures. Some of the cladding materials commonly used to deposit on plate of steel are copper, bronze, Aluminium, titanium, monel and other alloys.

6.2. Magnetic pulse welding (MPW)

In Magnetic Pulse Welding (MPW), magnetic forces generated from electromagnetic coils are used to produce welding in solid state. This process takes very little time in fraction of a second, very less heat input, Fillers or shielding gas are not used in this process.

Process:

The component with electrical conductivity to be welded is located inside the Electromagnetic coil based on the design. The Electromagnetic coil when energised forces one component impacting the other for more than 1mm at tremendously high velocity. The forces generated are the repelling forces between the magnetic fields produced by the eddy currents in workpiece and coil.

In Magnetic pulse welding, the electromagnetic pulse is of extremely short one lasts for less than a millisecond, and this pulse is generated by a quick discharge from capacitors using appropriate switch into the coil. The pulse produces a magnetic field of higher density. In one of the parts, the pulse generates an eddy current and Repulsive Lorentz forces are produced resulting one component impacting the other component. The impact pressure produced is more than the components' yield strength and a soft plasticity is achieved across the surface areas of impact. This plasticised deformed materials at interfacing leads to binding of the components in the solid state.

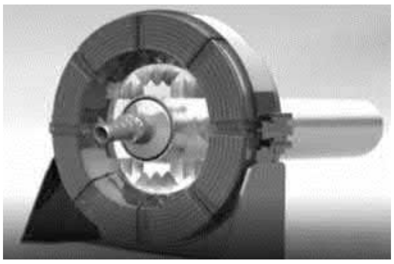

Figure 10: Magnetic Pulse Welding

In the process, no heat input and melting of the materials and this makes the technology applicable for joining of dissimilar materials.

Advantages:

- Weld are repeatable at faster rate
- Capable of Welding of many dissimilar materials
- No need for filler materials
- No or very less deformation
- High productivity and quality translate into significantly lower costs

Limitations:

- Mostly applies to roughly circular welds.
- Different coil designs for different components and the complexity of coil may increase as per the type of components to be joined.
- Process to be selected considering brittleness of the components as the impact produced in the process may damage the component
- Very high investment and may not be suitable for low volume batch production

6.3. Metal-to-Plastic Joining Methods

Several joining techniques are commonly used for the welding of metal and plastic workpieces. Some of the techniques are adhesive bonding, fastening, welding and other technologies. Each joining technique has its own benefits and limitations. The best technique is based on the application of the part and its working environment. Latest Techniques used in welding are discussed here.

6.3.1. Ultrasonic Welding

Ultrasonic welding is a widely used technology and is a solid-state welding method. The process uses the energy produced by high ultrasonic vibrations with very high frequencies and force applied for joining of the materials together.

This welding process involves less input of energy and joining takes place at surfaces in plasticised state with applied pressure. This technique is already discussed in detail in the previous sections.

Good study was carried out by researchers for ultrasonic welding of aluminium sheets with fibre-reinforced plastics. The study and experiments are related to the welding of aluminium alloy and fibre-reinforced plastics of one mm to two mm thickness sheets. The results are very encouraging, and the observations made were that the size of the weld is of forty microns mainly of thermoplastic resulting good binding of sheet metal with fibre. The binding is of aluminium adopting fibre material in the plasticised state and meshing between the two surfaces of contact, this has made the joint very strong.

6.3.2. Laser Welding

Laser welding process is well adopted in manufacturing of assemblies of all sorts. This process is used in all most all the sectors and industries. This process achieves strong metallic and chemical binding in metal to plastic parts.

LAMP (Laser-Assisted Metal and Plastic) A common process known as LAMP (Laser-Assisted Metal and Plastic) has been developed for joining between metals and plastics using the laser technology method. This process involves first cleaning of the surfaces of the parts to be joined using appropriate solution like alcohol. Generally metal sheet is placed over the plastic; however, if the plastic sheet is of more than 50% transparent then the plastic can be on the metal sheet. When the laser beam is focussed, typically bubbles forms on the plastic surface where it is contacting the metal surface as it is heated beyond the degradation temperature.

The advantages are very fewer joining times, very less input of heat, and the process is highly adaptable. Very good quality welding can be accomplished with the process joining of metal to plastics. This LAMP technique can be used very effectively for various combinations of metals like steels, aluminium etc. and plastics like pet, polycarbonate etc.

6.3.3. Friction Stir Welding

This process involves a non-expendable tool rotating at higher speeds is pushed on to the surface of the parts and the friction between the tool and the surfaces generates heat resulting plastic deformation and joining of the surfaces.

Conventional friction stirs welding encounters problems when welding plastics. These issues observed are due to the low thermal conductivity of the plastics and there is scope for improving the process.

6.3.4. Friction Spot Joining

Friction spot joining works on similar lines of linear friction stir welding and the difference being that linear motion is motion is not there absent in this case. In friction spot joining also the heat is produced due to the friction between the surfaces of the tool and parts.

Based on the axial movement of rotating tool, Friction spot joining can be of two types pin plunge and sleeve plunge while welding metals with plastics.

In sleeve plunging, the metal sheet is placed over the polymer which is placed over a backing plate and the two parts held with a clamping ring around the sleeve. Then the pin and sleeve start rotating – both in the same direction.

Then the sleeve is moved on to touch the metal part surface and the friction heat is generated between the tool and metal surface. The metal reaches plasticity state, and only sleeve is pushed into the metal surface forcing soft material into the sleeve below the pin thus forming a bead in the sleeve under the pin. In the next step, the sleeve is moved away from the metal part, and now the pin is moved towards the metal surface pushing the earlier formed bead on to the metal surface and refilling any cavity formed.

Friction spot welding can also be used for joining dissimilar materials like Al alloys and Mg alloys.

6.4. Plastic to Plastic Welding methods

Plastic to plastic welding process is of mainly three steps: heat input, joining force, back to normal temperatures. Joining is normally characterised by strong welds, very less operation times. There are several methods of plastic joining. The plastic joining methods vary mainly based on the source of heat.

6.4.1. Vibration Welding

In this process, friction is produced by the movement of one surface in relation to the other in straight or circular rotation. These friction results in heat input at the contacting surfaces of the component and joining of the materials takes place in soft state. Vibration welding has very small cycle timings, less than 5 s.

In comparison with the ultrasonic joining, vibration welds are with very lesser frequencies, but with larger amplitudes and higher joining pressure. Linear vibration joining is achieved with electro-magnetic equipment.

Advantages are:

- Smaller cycle times (approx. 20sec)
- Accurate dimensional control
- Strong Welds
- Hermetic seals

6.4.2. Impulse welding

Impulse joining is generally used for the films and is similar to the hot bar joining process, in which smaller dia. wire of Nickel Chrome with Poly Tetra Fluoro Ethylene film replaces the bar. Heat is produced by passing the current into the wire. This heating cycle is very short. The power is cut off, the wire is cooled very fast because of less heat input. The films are kept under force for a fixed cooling time.

6.4.3. Hot plate welding

This joining process involves, heating of surfaces to be joined by any of the 3 heat transfer methods or in combination of – Conduction-Convection—Radiation using a plate which is heat from a power source. Normally, the two components to be joined placed on the hotplate or nearer to it for sufficient time and the two heated component surfaces are clamped or pressurised after taking away the hot platen, to form joining between the parts. This process, normally have very less joining cycle times of maximum 20 Sec.

6.4.4. Spin Welding

This process is similar and seen as variant of friction welding. Friction is created between two surfaces of the parts to be welded by rotating one part in relation to the other. This friction heat input makes materials soft at contact surfaces and a firm joint is obtained under pressure. Spin welding have very less weld times maximum of 5 Sec. In the spin welding machines, pressure is applied normal to the surfaces where friction is created.

As in the Ultrasonic joining, in this process also, quality welding is obtained with Semi crystalline plastic materials. Using this process welding of dissimilar plastics is possible; however, the welding normally is not strong. This limitation can be overcome, by a proper weld design with an undercut, which is giving the space for the flow of the material with lower melting point.

Though the limitation of the process is that comp shape and welding areas need to be suitable for spinning, there are several advantages in using this technique. Spin joining gives strong welds with high quality, good sealing, low initial investment costs in comparison with other process equipment, operation is simple, easy and efficient operation.

6.4.5. Laser Welding

This is a contact less welding process. In the Laser welding process, laser beam is used as the source of heat input and for melting the material. The heating can be controlled through laser beam spot size and the location can be very precise. Almost all the thermo plastics can be joined using this process.

Laser welding can be automated, highly flexible and scalable – this can be used efficiently for a small batch manufacturing to mass production like in Auto motive industries. The controllability of the process parameters makes it as high precision welding process and quality welds can be achieved in the joining of plastic materials.

6.4.6. The Welding defects and their Testing methods

Though Welding defects and testing methods are beyond the scope of this paper, general defects and their testing methods generally used are given in the table below.

Flaws	Methods of testing
Dimensional	
Warpage	Visual inspection with proper mechanical gauges and fixtures
Incorrect weld size	Visual inspection with approved weld gauges
Incorrect weld profile	Visual inspection with approved weld gauges
Incorrect joint preparation	Visual inspection with proper mechanical gauges and fixtures
Discontinuities	
Porosity	Radiography, fracture, macroscopic, microscopic
Nonmetallic and other inclusions	Radiography, fracture, macroscopic, microscopic
Incomplete fusion	Radiography, fracture, macroscopic, microscopic
Undercutting	Visual inspection, bend test, radiography
Cracking	Visual inspection, bend test, radiography, Magnetic Particle penetrating, Liquid Penetrating Test
Surface defects	Visual inspection
Weld properties	

Flaws	Methods of testing
Low tensile strength	Tension test, fillet weld shear test
Low yield strength	Tension test
Low ductility	Tension test, free bend test, guided bend test
Improper hardness	Hardness test
Impact failure	Impact test
Incorrect composition	Chemical analysis
Improper corrosion resistance	Corrosion test

Table 3: Flaws and methods of testing

7. Adoption of Advanced Welding Technologies and Way-Forward for TCs and MSMEs

Introduction & implementation of Advanced Welding Technologies like Laser Beam Welding to Electron Beam Welding will create TC's unique identification in production & training area. As of now, there are no institutions providing training courses in this domain. Make in India program is going to push growth in the indigenous manufacturing in Defense sector and going to create abundant opportunities for supporting the manufacturing of avionics like Helicopters, jet fighters etc. and other components of Ships, Submarine etc. These advanced welding techniques are expected to find use in the process and power industries also. Current research in the automotive sector for lighter vehicles shall make these techniques to grow exponentially. EV development, wherein special materials have to be joined using the advanced welding methods, will spur the demand of the services. In nutshell, these welding technologies are going to be dominant in the "Precision Manufacturing' sector and the manufacturing potential shall create a high requirement of trained manpower.

While training and providing services, the TC should maintain a database of the operating parameters used in mapping with the results, materials, depth of penetration, metallurgy, quality etc. This database shall also help in the design of components and selection of processes during the design & development of components. This will assist in Computer Integration and modelling of the jobs and simulation. Simulation tools are needed to predict material reaction to both the welding process and the conditions the weld will face in various applications.

Considering the services in Automotive, Aerospace, Marine and to motivate SMEs to adopt these technologies, the following machines are suggested for TCs:

7.1. Laser Beam Welding machine

For TCs, Yb-fibre laser machine with power 4kW or better is recommended. Laser welding technique is more versatile and flexible and used in almost all sectors. In Aerospace and other industries, Laser welding is predominantly used and exploited to full potential. The introduction of Laser welding machine may facilitate entry or enhance the scope for services into Aerospace industry for the TC including some of the manufacturing opportunities.

The laser welding has very wider applications and in almost all type industries. Some of the components manufactured using the laser technology are - transmission components, engine components like valves and pistons, alternator components, fuel injector's components, filters for fuel, airbags and several other components.

Laser Welding is used extensively for roof panels welding. Future light-weight apt designs of auto parts of Aluminium, Magnesium, Plastic and other parts can be welded with this Laser technology.

Laser welding can be used for continuous leak proof welding.

Aerospace industry is one of the biggest users of Laser Welding. Services can be provided for the production of sub-assemblies of Barrels, Floor Grids, Rails etc.

7.2. Training in Laser Welding Technology

Laser welding technique needs skilled manpower. Currently, there is a heavy shortage of manpower with these skills. There are very few institutes which offer training in the operation of the Laser Welding Machine. The training also should cover Laser Parameters, Welding parameters as per the material and depth control.

7.3. Friction Welding Machines

There are three types of machines which are recommended for TCs:

- Friction Stir
- Linear Friction
- Inertia Friction machines

These machines are mostly in the wish list of almost all fabrication manufacturers; however, their prohibiting cost discourages them to make the purchase. These machines can be used for production as well as training.

Major applications areas of friction welding machines

- Railway industry - bogies (sheets of aluminum)
- Aerospace- Fuselage and various turbine components
- Automotive -
    - Truck framings and body structures
    - Wheels, Suspension arms and Fuel tank
- Electronics – panels and Heat sinks
- Ship building – several types of panels in boats and ships
- Pipelines and heat exchangers
- Electrical motor housings

7.4. Training in Friction Welding

Friction Welding processes are going to be more and more popular because of their inherent processing properties and it is estimated that there will be severe shortage of skilled manpower in Friction welding techniques. There are several benefits of friction welding's such as strong quality weld, it is highly productive with or without automation and most intended technology to adopt. The TC should initiate training Programs in this advanced welding technology to support the industries. The training should also include aluminum and other metals welding metallurgy; operation of Friction Welding machines and tooling required; process control; materials weldable; design implications of these Friction Welding techniques.

7.5. Electron Beam Welding Machine

Electron Beam Welding machine is not recommended, as of now considering its cost and overall services opportunities, though this technology is being used extensively in Aerospace industry and to some extent in Automotive mainly due to the cost factor. However, Training programs should include this technology as well.

Linkages for Advanced Welding Technologies: TC should take initiative to tie up with the leading manufacturers for getting sponsored and continuous projects for enhancing the applications and designs. These processes furthermore need dedicated fixtures and tooling which can be developed by the TC. Projects can also be taken up to develop advanced sensors which play key role to control the machine parameters, placement and quality of the joining.

8. Conclusion

Global trends are giving good thrust in the automobile and aerospace industries to redesign and rediscover their methods of manufacturing. The industries are racing to develop innovative materials and methods to maximise efficiency. Further, to increase efficiency of the equipment, various new optimised designs of new combination of materials are being implemented as never before. Lightweight concept vehicles are being strongly advertised and is forcing the use of materials like aluminium, fibre plastics, stronger materials, newly developed plastic and bi-metallic materials throughout the vehicle - frames, panels, structures, engine transmission, interiors and exteriors. Plastic materials including fibre reinforced plastics, combination of metal and plastic are the first choices for weight reduction, however, this may lead to issues and challenges for welding the dissimilar materials. These processes may demand advanced welding technologies like joining metal to metal parts or plastic to plastic parts or metal to metal components.

Already numerous SMEs have upgraded and are capable of CO_2 Laser welding, and few units are equipped with ultrasonic welding machines and other advanced technology machines. This up-gradation is not enough, not only for meeting the future challenges but also to meet the quality requirements.

Availability of skilled manpower is a challenge being faced across the globe is the major issue behind the high automation and embracing the latest welding technologies in all major sectors and industries. Besides this, though the initial investment is higher in implementation of new technologies; more productive latest welding techniques and associated processes like controlled welding, smart feedback and correcting devices etc. are helping manufacturers to increase their efficiency, adoptability and quick ROI.

Laser Beam Welding technologies of different methods like Gas lasers (CO_2 and others); Electron Beam Welding and Friction Welding technologies like Friction Stir welding, Linear Stir Welding and Inertia Stir Welding; and Ultrasonic Welding can be used for dissimilar metals also very effectively. These latest welding technologies are ecologically - friendly and energy efficient. Further there are various joining methods for joining dissimilar metals; Metals to Plastics; Plastics to plastics.

With discovery of new materials, new designs and new processes, the future of the welding industry lies in the adoption of these welding techniques in the fabrication and developing the skills. Though the initial investment is involved, increase in the productivity of the welding processes and lack of alternate methods may enable quick return of their investments. SMEs have to prepare to adopt the latest welding technologies as a way forward. TCs need to adopt these new technologies to support SMEs by trainings and support in services.

Annexure 1:

Advanced Welding Methodologies and their Usage in Materials

Type of Welding	Same Metal	Dissimilar Metals	Dissimilar Materials	Metal-Plastic	plastic-plastic	Thickness *
Laser Beam Welding	YES	YES	YES	YES	YES	3mm
Electron Beam Welding	YES	YES	YES	YES	YES	0.01 - 250 mm Steel 0.01 - 500 mm Al
Friction Stir Welding	YES	YES	YES	Process yet to improve	Process yet to improve	0.5 to 65 mm
Linear Friction Welding	YES	YES	YES	YES	YES	Machine size limitation
Inertia Friction Welding	YES	YES	YES	YES	YES	Machine size limitation
Laser Arc Hybrid Welding	Steels	To some extent	X	X	X	6mm to 15mm (even to- 50mm)
Laser MAG Hybrid Welding	Steels	YES	X	X	X	10 mm
Laser MIG Hybrid Welding	Steels	YES	X	X	X	10 mm
Laser TIG Hybrid Welding	Steels	YES	X	X	X	10 mm
Ultrasonic Welding	YES	YES	YES	YES	YES	2.5mm 1 mm for Harder

Material Types	Popular Weldings
Clad and Metal-Non-metal	Explosive welding
	Magnetic Pulse Welding (MPW)
Metal - Plastic	Ultrasonic welding
	LAMP (Laser-Assisted Metal and Plastic)
	Friction Stir Welding
	Friction Spot Joining

Material Types	Popular Weldings
Plastic - Plastic	Laser Welding
	Ultrasonic welding
	Impulse welding
	Vibration Welding
	Spin Welding
	Hot Plate Welding

Note: * Thickness given is Approximate figures - as Sheet thickness depends on the welding technique, machine parameters as well as the material[9]

[9] References: Keyence; Millerwelds; Slideshare; Dukane; twi-global; Industrial-lasers; weldingengineers,NZ; tandfonline; bmax

Annexure 2:

Recommended machines and services in advanced welding technologies for Technology Centres:

Sr.No.	Recommendation	TC - Services, Support to MSMEs & Opportunities in Precision Engineering - Automotive and Aerospace Sectors	Applications in Other Sectors/Remarks
1.	Laser Beam Welding Machine – Yb-fibre laser machine with power 4kW or better is recommended	• TC can support MSMEs and take up production services for manufacturing various automotive parts • The laser welding has very wider applications and in almost all type industries. Some of the components manufactured using the laser technology are - transmission components, engine components, alternator components, fuel injector’s components, and several other components. • Laser Welding is used extensively for roof panels welding. Future light-weight apt designs of auto parts of Aluminium, Magnesium, Plastic and other parts can be welded with this Laser technology. • Laser welding can be used for continuous leak proof welding’s. • Aerospace industry is one of the biggest users of Laser Welding. Services can be provided to produce sub-assemblies of Barrels, Floor Grids, Rails etc.	• Laser Welding is intensely used in Electronic, Medical Equipment and Food Processing industries • LBW is also used for spot welding and Vacuum components. In shipbuilding, sector Hybrid Laser-Arc and Laser-MIG/MAG welding’s are used for more than 30 m long welding’s extensively.

Sr.No.	Recommendation	TC - Services, Support to MSMEs & Opportunities in Precision Engineering - Automotive and Aerospace Sectors	Applications in Other Sectors/Remarks
2.	Training in Laser Beam Welding - technology and operation	• Training Laser Beam Welding: Laser welding technique needs skilled manpower. Currently, there is a heavy shortage of manpower with the skills. • There are very few institutes which offer training in the operation of the Laser Welding Machine. The training also should cover Laser Parameters, Welding parameters as per the material and depth control. With the introduction of this training, the TCs can become the pioneer in training and will fulfil the image of leading training institutes. • Very good demand and opportunity for the TC for training on Laser welding	The demand for skilled manpower is going to surge if the precision auto parts in the development stages come into the production.
3.	Friction Stir Welding Machine	• The welding capability of the process of Aluminium alloys – is having wider ranges and a max. thickness of ~75 mm is possible and even for Aluminium and Lithium alloys; and Dissimilar materials of Cu-Al; Al-Mg; Al – Al alloys; Mg – Mg alloys is going to create plentiful production and business opportunities. • Production and Support to Automotive Sector in the manufacturing of: Truck bodies, caravans and space frames; Wheels; Suspension arms and Fuel tank items	In other industries various parts which can be manufactured are: Locomotive bogies and carriage panels (aluminium) Electronics- cover panels, shipbuilding-Boats and ships' panels Pipelines and heat exchangers Electrical motor housings

Sr.No.	Recommendation	TC - Services, Support to MSMEs & Opportunities in Precision Engineering - Automotive and Aerospace Sectors	Applications in Other Sectors/Remarks
		In Aerospace precision manufacturing of: Aircraft fuselage and avionics parts. This facility may even create an entry opportunity into the major manufacturers of the Aerospace industry	
4.	Training in Friction Stir Welding - technology and operation	• Training in Friction Stir Welding: A Friction Stir Welding process tends to grow more at a higher rate due to its processing properties. It is expected to have a severe shortage or currently little skilled Manpower in Friction Stir welding techniques. • TCs should initiate training Programs in this advanced welding technology to support the industries including MSME units. The training should also include aluminium and other metals welding metallurgy; operation of Friction Welding machines and tooling required; process control; design implications of these Friction Welding techniques.	• The training should also include welding of various other materials not in use currently but are going to be dominant in the future like Magnesium copper etc. • However, Metal to plastic welding is observed as not perfect - development of process or tools are needed.

Sr.No.	Recommendation	TC - Services, Support to MSMEs & Opportunities in Precision Engineering - Automotive and Aerospace Sectors	Applications in Other Sectors/Remarks
5.	Linear Friction Welding Machine	• The main strength of this process is Forged-quality welds for complex geometries of nearly any material type. The welding can be of the plate to plate; plate circular pipe or any shape gives a lot of flexibility. • In the Automotive industry: Bumper and other components are welded. In the Aerospace industry: Manufacturing of Blisks is done with this process exclusively as it reduces the weight and cost. Usage of this established process extended to the manufacturing of other parts like blade discs in power and compressor equipment	• In-Process and Power sectors: Manufacturing of the turbines, fans in compressor etc. Similar manufacturing can be extended to Ship-building sector also.
6.	Training in Linear Friction Welding - technology and operation	• Training in Linear Friction Welding: It is expected to have severe shortage of skilled Manpower in Linear Friction welding techniques. The TC to initiate training Programs in this advanced welding technology to support the industries including MSME units. Training to include the various control factors like force and time to apply on the components of various materials.	• The training should also include welding of various other materials not in use currently but are going to be dominant in the future like, Magnesium copper etc.

Sr.No.	Recommendation	TC - Services, Support to MSMEs & Opportunities in Precision Engineering - Automotive and Aerospace Sectors	Applications in Other Sectors/Remarks
7.	Inertial Friction Welding Machine	• This process has become very popular and the use of Friction welding has increased tremendously. There are very good business opportunities for TC in the manufacturing of the components using this technology to support MSMEs as well as in its production. • In Precision Automotive Sector: Stabilizers, Engine components like valves and pistons Driving shafts and other components In Precision Aerospace Industry: Titanium - Rotor Assembly and Cluster Gear and others	This is the most popular method of the three Friction welding techniques. This technique found its way in all the manufacturing sectors where welding strength required is of parent material and shapes permit to adopt this technology.
8.	Training Inertial Friction Welding Machine - technology and operation	Training in Inertia Friction Welding: There is severe shortage of skilled Manpower in Inertia Friction welding and the machine operation. The TC to initiate training Programs in this advanced welding technology to support the industries including MSME units. Training to include the various control factors like force and time to apply on the components of various materials.	
9.	Electron Beam welding machine	Electron Beam Welding machine is not recommended, as of now considering its cost and overall services opportunities, though this technology is being used extensively in Aerospace industry and to some extent in Automotive mainly due to its costing factor. Even	Research is going on to implement this technology without vacuum chamber which is high cost contributor of the machine and operation. If this is successful, it is expected to find its way like Laser Welding as high depths of welding's are achievable like 0.01mm-250mm in

Sr.No.	Recommendation	TC - Services, Support to MSMEs & Opportunities in Precision Engineering - Automotive and Aerospace Sectors	Applications in Other Sectors/Remarks
		globally, the population of this machine in MSMEs is very little.	Steel and 500mm in Aluminium
10.	Training Electron Beam welding technology	Training programs should include this very important Welding Technology except for the operation of the machine, overview of the technology, parameters to control to achieve quality welding's with popularly used and important materials, and limitations.	Controlling of the electron beam is very critical to achieve the required depth and quality of the welding. The training to focus on this aspect also
11.	Training in Ultrasonic welding technology	This process is gained its own importance and popularity especially in joining Plastics-Plastics. However, the availability of trained and skilled manpower is very less. Many numbers of units have implemented this welding method. The TC is to introduce full-pledged training in Ultrasonic welding except for machine operation. The controlling factors like the direction of oscillations in case of plastic-plastic and plastic-metal welding's, vibration frequencies as per the material, force applied, hold time and other factors.	The ultrasonic welding market is growing as the adoption of plastic parts has increased in the Automotive sector and the important factor is that the trend is growing.

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