Recent Trends in Laser Welding

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1. INTRODUCTION

Laser Matrial Processing technology has deeply penetrated into various industrial applications since 1966(1) when the first industrial CO_2 Laser was built. Since then the versatility and importance of Laser in material processing has been gaining recognition and acceptance with the result that many industries in the developed countries utilise Laser systems. This has encouraged further investigations into the improvement processing methods using Laser to overcome the presently confronted difficulties.

Laser is the versatile tool both for metals and non-metals and as a single heat source it can perform multifunctions given below, which is not possible by any other heat source :

i) Welding
ii) Cutting
iii) Drilling
iv) Machining or Trimming
v) Brazing and Soldering
vi) Engraving or Scribing
vii) Surface hardening
viii) Surface cladding or alloying
ix) Glazing

This document deals with all aspects of 'Laser Welding' alone and not with other 'Laser Material Processing' applications.

1.1 Theory of Lasers

Laser is an acronym for Light Amplification by Stimulated Emission of Radiation. The lasing action can be broadly split into two phenomena.

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(i) Stimulated Emission of Radiation

When energy is supplied to atoms in the ground state by intense flash of light or an electrical discharge, then the electrons of the atoms acquire higher energy levels by absorbing the energy. The energy levels of absorption/emissions are characteristic of the atomic number of the element. These electrons in their effort to come back to their ground state or lower energy levels emit radiations of characteristic frequency and wavelength (Fig-1)

The wave length of each photon emitted is related to is energy (E) by $\lambda = ch/E$, where c is the velocity of light: h=Planck's constant.

These photons while passing close to another excited particle, stimulate the emission of radiation of same wave length, phase and spatial resolution (Fig-2). These photons, in turn, are also capable of stimulating emission of radiations.

(ii) Amplification

The lasting medium is contained within a sealed cavity consisting of highly polished and paralled mirrors (Fig-3). Lasing is possible when enough photons are present. The emitted photons are reflected by

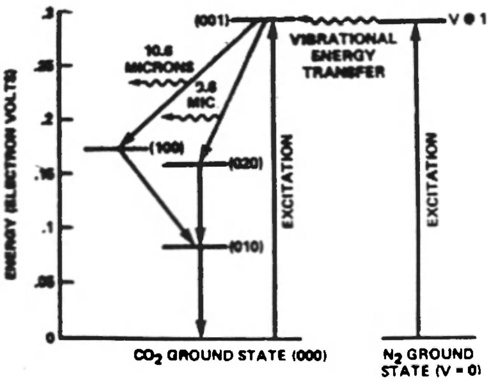


Fig. 1. *Energy levels of the CO_2 system (1)*

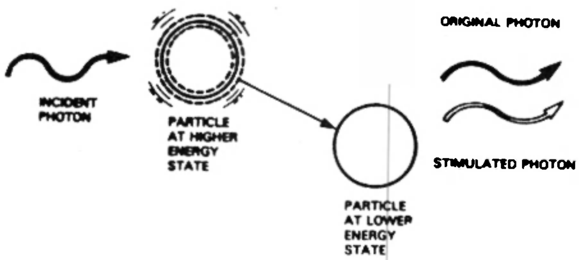


Fig. 2. *Stimulated emission*

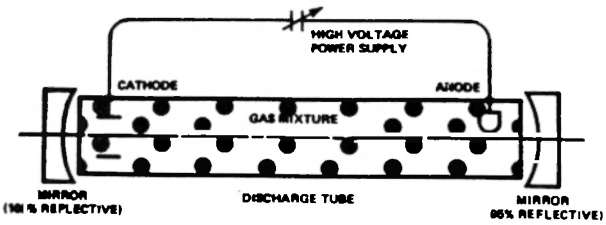


Fig. 3. *Basic CO_2 laser configuration*

these mirrors back and forth in the cavity and enabling them to stimulate further emissions of photons. Thus the number of photons in the cavity keeps on increasing. The photons travelling normal to the parallel mirrors are multiple reflected between the mirrors (Fig-4). Some of these photons pass through the partially transmitting mirror located at one end. These photons emergy as coherent, single frequency light radiation in the tube while the other photons continue to oscillate in the cavity generating more photons.

1.2 Industrial Lasers

Some of the important industrial Lasers, their wave lengths, power ranges and material processing applications are tabulated in Table - 1.

2. LASER WELDING

Welding is accomplished with Laser by the application of concentrated coherent light beam on the surfaces to be welded. The thermal energy of the laser is precisely controllable in intensity and position. The high concentration of energy on small spots produce high intensity of energy which causes the material to melt. Joining is basically two kinds of industrial Laser beam welding(LBW) processes - i) condition limited and ii) deep penetration.

(i) Conduction limited welding

In this method, the metal absorbs the incident beam on the surface and the heat is conducted through the metal to the subsurface region. This reduces the capability of the process for welding thick material and the depth of penetration is limited. Conduction limited LBW utilises solid state and moderate power CO_2 Laser and is normally performed with low average power. The weld structure/shape is hemispherical due to the uniform thermal conduction in all directions.

(ii) Deep penetration welding

This method utilises high power continuous wave CO_2 Laser. The incident laser beam of high intensity melts a small cylindrical volume of metal through the

Table - 1

LASER TYPE	WAVE LENGTH μ m	POWER kW	PRINCIPAL USES
He-Ne	0.63	10'	METROLOGY, SURVEYING
Ga-As	NEAR INFRA-RED	...	OPTICAL COMMUNICATION
CO_2	10.6	$\leq$ 0.1 0.1 - 0.5 1.0 - 5.0 $\geq$ 10.0	CERAMIC SCRIBING, CUTTING, DRILLING WELDING, SOME CUTTING APPLICATIONS HEAT TREATING, HEAVY SECTION WELDING, CUTTING LARGE SCALE HEAT TREATING, CLADDING, ALLOYING
Nd-YAG (Pulsed)	1.06	0.05 0.1 - 0.4	SPOT WELDING, SMALL HOLE DRILLING & SOLDERING. SEAM WELDING, HIGH SPEED SPOT WELDING, CUTTING LARGE HOLE DRILLING
Nd-YA (Continuous Wave)	1.06	$\leq$ 0.1 0.2 - 0.8	CERAMIC, SCRIBING, RESISTOR, TRIMMING, DIAMOND, SAWING, NON CONTACT MARKING WELDING & HEAT TREATING

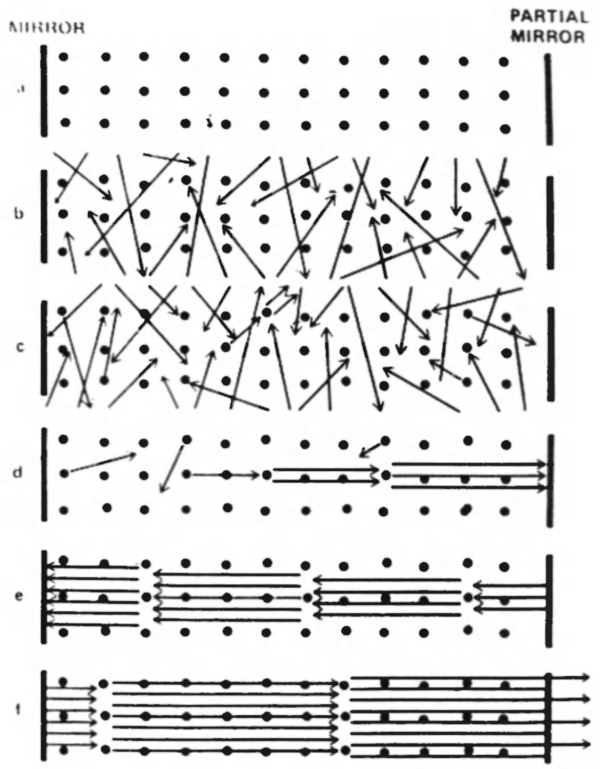


Fig. 4. *Events in laser resonator*

thickness of the material. A column of vapour is trapped inside this volume surrounded by molten metal. As the beam is moved along the joint the column moves along with it, melting the metal in front of the column through its depth. The molten metal flows along the base of the column and solidifies on the trailing end. The vapour column is stabilised by a balance between the energy density of the Laser beam and welding speed. This method is also known as keyhole welding. This is capable of producing greater penetration. One more advantage of this process is that, due to preferencial heating, the impurities in the metal are evaporated and escape as vapour, thus purifying the weld. Such welds also have high depth to width ratio.

2.1 Influence of Various Parameters on Laser Welding

In welding, the main point of attention in Laser beam and material interaction is absorption. It is the absorbed energy which contributes to the melting of the metal and hence directly relates to the efficiency of the process. The process parameters which influence the results of the process i.e. penetration depth and quality of weld are

(i) beam power
(ii) beam diameter
(iii) welding speed
(iv) focussing conditions
(v) TEM mode

2.2.1 Absorptivity

During the welding of metals, the main problem which arises is the reflectivity of the metal. Metals having high reflectivity do not absorb the requisite energy for fusion and consequently welding. Hence, we have to optimise the factors affecting reflectivity/absorptivity so that absorption is maximum. The factors governing reflectivity are

(i) wave length of incident beam
(ii) angle of incidence of beam
(iii) polarisation of the beam
(iv) temperature of the material
(v) physical and chemical properties of the matrial

Different materials exhibit varying reflectivity at different wave length of incident light, e.g. most metals are highly reflective to 10.6 μm wave length CO_2 Laser and comparatively less reflective to 1.06 μm wavelength Nd-YAG Laser. Linearly polarised light probably has some detrimental effects on welding.

The absorption of the radiations by metals depends on the conductive absorption by free electrons, hence the absorptivity is related to the electrical resistivity of the material. Electrical resistivity is itself a function of the temperature of the material. The absorptivity of polished surfaces of various materials was found to be directly proportional to the square root of the resistivity. The absorption increases with rise in surface temperature and rises rapidly in the molten state and remains high in the vapour state of the material. Absorptivity increases at higher power densities for materials which are highly reflective at lower power densities. This is due to keyholing. The cylinderical vapour cavity surrounded by molten metal acts as a blackbody and absorbs the incident beam which undergoes multiple reflections at the walls of the cavity e.g. For Al,which has an initial absorptivity of 2% at 10.6 μm, keyholing results in an absorption of 60% or more.

2.1.2 Beam Power

A minimum threshold power is required for Laser welding of given thickness with a beam of specified diameter. The penetration increases almost linearly with incident beam power.

2.1.3 Beam Diameter

For a given power, the beam diameter defines the power density. A gaussian beam diameter is defined as the diameter where the power is $1/e$ or $1/e^2$ of the central value. The diameter corresponding to $1/e^2$ of the power at centre is recommended as it contains

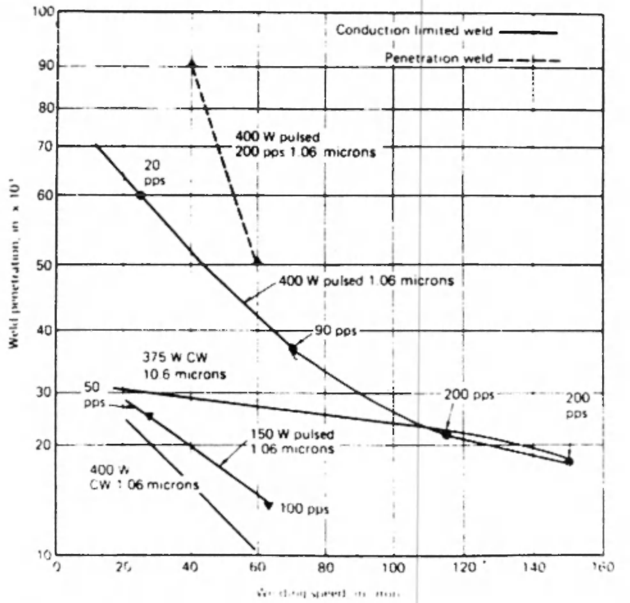


Fig. 5. *Effect of welding speed on penetration on a 300 series stainless steel*

more than 80% of the total power. The diameter in the focal plane depends on the diameter and the focal length of the lens being used.

2.1.4 Welding Speed

In general for a given power output, an increase in welding speed causes a decrease in the depth of penetration. Consequently, if higher speeds are sought for the same depth of penetration then higher power outputs are required. The variations of penetration depth change in speeds are shown in Fig. 5. Welding speed is specifically critical in deep penetration welding. The vapour column is stabilised by the proper combination of energy density and welding speed. Too high speeds result in incomplete penetration and too low speeds results in wide fusion zones and sometimes drop-through.

2.1.5 Focussing Conditions

The laser beam emerging from the focussing lens converges in the direction of propagation and attaining a minimum diameter and diverges beyond this region. This diameter is attained at its focal length from the lens. Fig. 6 depicts the situation.

For a small distance ±d on either side of the focal plane the variation of beam diameter is very small and the power density is practically constant and a max. over that region. This region usually defines the working region for material processing. Beyond ±d, the intensity may reduce below the threshold surface of the material as greater part of the high intensity region interacts with the material. With higher focal length lenses the depth of focus is greater and vice versa.

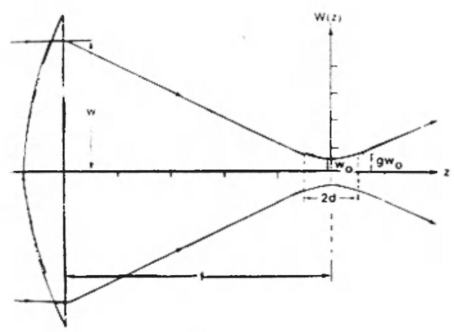


Fig. 6. *Beam focussing for TEM00 mode*

$$\theta_{ff} = \frac{\lambda}{\pi w_o} \qquad (11)$$

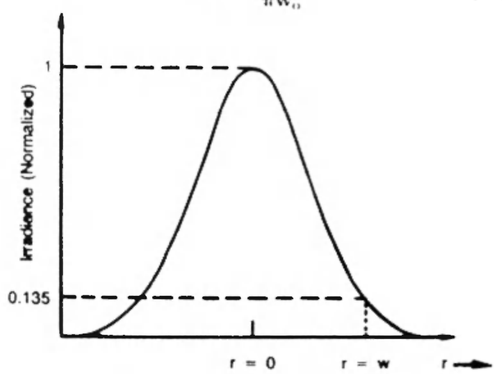


Fig. 7. *Gaussian (TEM00) intensity distribution*

From earlier results, it was proved that the penetration was greater when the focal plane was positioned slightly below the surface of the material. The correlation between power density and depth of focus and their effect on penetration has been studied. It was found that maximum penetration for higher power densities occurred at deeper focal points, suggesting that to obtain maximum penetration with increase in power density the focal point has to be sunk deeper into the metal. They also found that for a given density, the position for which the maximum penetration occurred was invariant of the speed.

2.1.6 TEM Modes

The oscillations of photons between the resonators in the Laser cavity form an intense electromagnetic field. This field can have many cross-sectional shapes termed as transverse electromagnetic modes (TEM modes). In general, it is represented as TEM mn mode where m and n specify the integral number of transverse nodal lines across the emerging beam.

The simplest mode is TEM oo with a gaussian energy distribution through its cross section. It is the ideal mode for welding as most of the energy is concentrated at the centre of the beam. Other modes (e.g. TEM 01) do not have the focussability as that of TEM00. Thus proper selection of the modes is necessary for the specific material processing application. Fig. 7 shows the energy distribution for TEM00 across the cross section.

2.2 Advantages and Limitations of Laser Welding

Many advantages of laser welding are given below:

(1) The high intensity of Laser beam radiation has made it possible to weld materials with narrow deep penetration.

(2) The small spot diameter of focussed Laser gives high intensity which allows the weld to be superior with a very narrow heat affected zone.

(3) Laser welding can be done at room temperature and pressure without necessity for pre-heating and vacuum atmosphere.

(4) The rapid heating and cooling rates of the weld in LBW results in fine grain structure in the weld region thus enhancing the strength of that region.

(5) Difficult materials such as Ti,quartz and ceramics can be welded.

(6) The work piece need not be clamped rigidly

(7) No electrode or filler material is required.

(8) Intricate shapes can be welded using light deflection techniques.

(9) Time sharing and beam splitting of Laser beam can be achieved.

(10) Higher welding speeds can be achieved by Lasers than conventional methods resulting in reduced distortion due to minimum residual stresses.

Limitations of Laser welding are given below when compared with conventional arc welding processes and competing electron beam welding.

(1) High capital cost, when compared with conventional arc welding processes.

(2) High inventory cost of optical spares towards maintenance of the equipments.

(3) Equipment efficiency and process efficiency both are lower when compared with electron beam welding (EBW).

(4) Joint preparation without gap and alignment of the beam on the joint are critical.

(5) Surface reflectivity and plasma formation above the surface limit the capability of the process.

2.3 Laser Welding of Industrial Materials

2.3.1 Steels

Welds have been formed in SS with aspect ratios as large as 12:1. With SS, high density, non-porous welds can be achieved. Tensile strength of the SS welds can be equal to that of the parent material. The Laser welds in HSLA were found to have equal mechanical properties as that of the parent material in contrast to the arc welding techniques. Laser welding was found to be the only method capable of welding tin free steel. Successful, autogenous, square butt welds of X-80 arctic pipelines steel using a high power cw CO_2 Laser is reported. Both single pass and dual pass techniques are used to weld 13.2 mm thick material.

2.3.2 Ti and its alloys

Ti is a chemically sensitive metal and has a complex temperature dependent structure. Laser welds of Ti (upto 5 kW laser power) showed no cracks, porosity or inclusion. The tensile strength of the weld is almost equal to that of the parent metal. Welding speeds in excess of 15m/mm, were obtained for 1mm thick Ti-6Al-4V alloy was conducted. Radiographically sound welds were produced by all three techniques. Laser welds were narrower than arc welds and were comparable to, but more uniform than EBW weld beads.

2.3.3 Aluminium and its alloys

The high reflectivity of the surface of Al and its alloy has posed immense problems in Laser welding of these materials. They are highly reflective to 10.6*m radiation from CO_2 Laser. Unacceptable amounts of porosity in all weldments and excessive drop through was observed for full penetration depths. When the shielding gas was so directed that the plasma was pushed into the keyhole, it resulted in porosity free welds.

3. DEVELOPMENTS OF LASER WELDING TECHNIQUES

3.1 Laser Beam Pressure Welding

The Laser beam pressure welding is a new welding technique which allows to weld with very high speed and minimum of defects. The principle of Laser beam pressure welding was discovered when efforts had

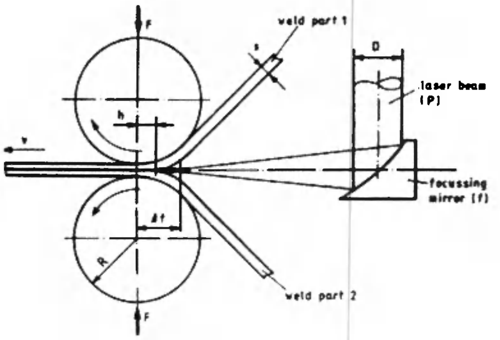


Fig. 8. *Schematic diagram of laser pressure welding of sheets*

been done to avoid defects in laser welds originating in the melt. The idea was to suppress melting or squeeze melt out of joint before it resolidifies. This is possible by heating up the region of welding parts (work pieces) with the focussed laser beam and at the same time pressing them together. The point of impingement should be as near the contact region of the weld parts as possible. In this way, the welding zone is heated directly without any mechanical contact and without heat conduction through work pieces. The heat is concentrated in the joining area itself. This area is made small because of the high power density of focussed laser beam. Another important point is that no melt is needed for the welding process. It only require high temperature, a temperature for hot working near the solidus temperature of the meterial. If melt is produced, it is squeezed out mechanically by the forces of pressure rolls. One possible arrangement is given in Fig. 8. In the industry, this technique has been used for tube welding, T profile butt weld and welding of difficult materials like brass, cr-coated foils etc (Fig. 9).

The salient features and advantages of this technique are:

(i) Materials with no or poor electric conductivity should be weldable because of direct heating of welding zone by Laser beams.

(ii) Very high welding speeds possible because of direct heating up welding zone with high power density (experiments have been done for speeds upto 240 m/min)

(iii) Because of high speed, low heat input is realised.

(iv) Because of high power density and high speed narrow HAZ is obtained.

(v) Welding defects like pores, solidification cracks, or irregularities of weld surface are not present.

(vi) Coated materials can be welded.

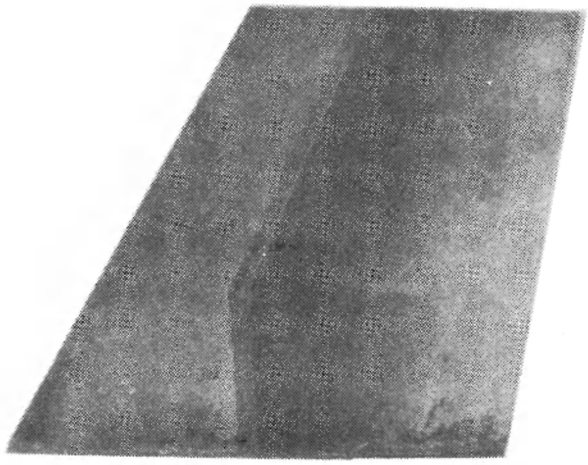


Fig. 9. *Laser Pressure welding of austenitic stainless steel of T-Profile*

Thickness	:	*3mm/1mm*
Power	:	*4KW*
Speed	:	*70m/min*

(vii) Metallurigical effects of high cooling rates would be used for processing 'difficult' materials.

(viii) Mechanical tests have been shown that weld is stronger than base metal.

There is a distinct disadvantage with this process. Due to large temperature gradient with increase in depth, it is not very suitable for crystalline metals like high carbon steels.

3.2 Laser Welding with Wire Feed

Autogenous welding of butt joints usually results in severe undercuts which places closer tolerance limits on joint preparation. The use of wire as filler material eliminates undercut and produces reinforcement of the weld (Fig. 10). Work has been done in the investigation of the effect of welding speed, wire feed rate and gap at the joint on the quality of the weld.

Trails on a 1.9 kW Laser with transverse speed of 1.2 m/min, argon plasma shielding at 15 l/min and wire feed position at 1.2 mm in front of the Laser beam were carried out. The conclusions from the trails were:-

(i) A constant wire feed rate can overcome mild variations in gap geometry.

(ii) Higher feed rates build up a top bead at the expense of penetration.

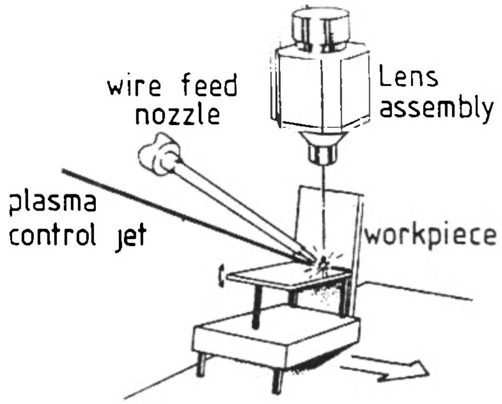


Fig. 10. *Laser welding with wire feed-experimental set-up*

Multiple pass deep penetration welding has been possible by wire feed method and also, weld metal composition can be varied by using filler wires of suitable compositions.

3.3 Laser Welding with Metal Powder as Filler Material

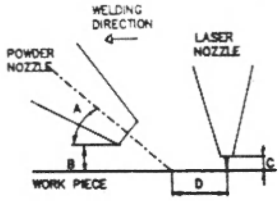
The automobile industry puts very high demand on the smoothness of non-covered joints. It has been found that butt welding of thin sheet metals leads to undercut due to the small gap. Present day methods of using wires as filler material are found to produce unacceptable big reinforcement of the weld. The requirements for the industry were, a joint with moderate reinforcement of the weld and a minimum heat input.

Keeping these requirements in mind, the use of powder as filler material was attempted and the effects on joint quality and reinforcement investigated. The process utilised a 2.5 kW cross flow CO_2 Laser with co-axial gas shielding. The powder material is fed preferencially into the gap of the joint, the principle of stray magnetic flux between the gaps of the joint was used. The work pieces made to be a part of a magnetic polarisation of the edges and hence the powders are preferancially collected in the gap. The results from the experiments concluded that:

(i) 1mm thick sheet metal can be butt welded without joint preparation by adding powder filler material.

(ii) Satisfactory welds could be obtained with weld gap of 0.4 mm.

(iii) The optimum gap which gave the maximum powder collection for the set experimental parameters was 0.2 mm.



A: POWDER NOZZLE ANGLE (deg)
B: POWDER NOZZLE HEIGHT (mm)
C: LASER NOZZLE HEIGHT (mm)
D: POWDER JET DISTANCE FROM THE LASER FOCAL POINT (mm)

	A	B	C	D
1	37	10	5	22
2	60	10	5	58

Fig. 11. *Laser welding with metal powder as filler materials*

(iv) The larger the joint gap, the lower the welding speed limit.

(v) The largest gap which could be satisfactorily welded without powder was 0.2 mm, whereas that with powder was 0.4 mm.

3.4 In-vacuum Laser Welding

Laser welding at reduced pressure has been investigated and the results have been found to be favourable. It was found that as the chamber pressure was reduced., the depth of penetration got increased. The reasons for the increase in penetration was attributed to the reduction of plasma screening. The Laser beam welding was also found to be much more stable. In-vacuum Laser also found to be much more stable. In-vacuum Laser welding increase keyhole stability and permits operation at much more lower welding speeds than possible at atmospheric pressure. Penetration of the order of 19 mm was obtained with only 3.4 kW but only at 0.2 mm/sec. speed. With 5 kW laser, and 0.34mm/sec. speed 41 mm deep weld could be made.

The penetration curve is found to saturate after below a pressure of 10^2 torr. It has been found that Laser welding in reduced pressure at slow speeds greatly increases the penetration. Experimental at different external pressure and translational speeds were performed. The results are illustrated in Fig.12 & 13 for SS (304) and Ti-6A1-4V respectively. The problems encountered in such a process were undercut and surface roughness. Osillation of the Laser beam has been proposed as a remedy for these problems on the basis that such a method eliminated these defects in electron beam welding.

Substantial welding thickness (3-5mm) SS and Ti sheet were obtained by reducing pressure (around 10 torr). But the speed of welding required to be slow.

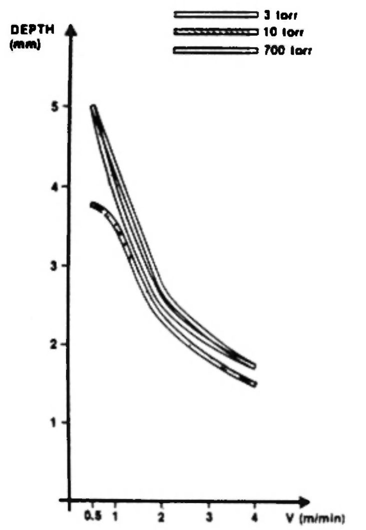


Fig. 12. *Laser welding of AISI 304 in vacuum-welding speed vs penetration depth*

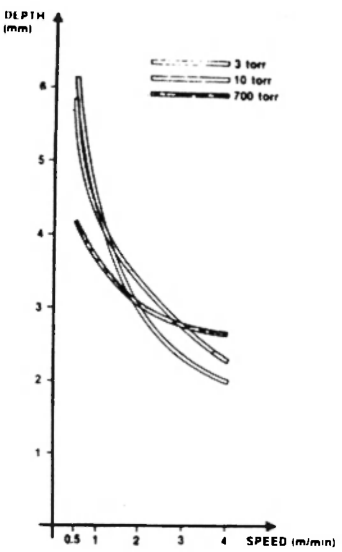


Fig. 13. *Laser welding of TI-6AL-4V in vacuum-welding speed vs penetration depth*

3.5 Thick Plate Multipass Welding

Welding of 50 mm thick plate, which requires 100 kW class Laser in single pass welding, is demonstrated with 5 passes at 10 kW power level with satisfactory bead geometry. Thicker plates above 20mm have not been welded so far by industrial CO_2 Laser due to limitation of equipment power rating of 25kW (commercial availability) and severe plasma formation screening the beam and the substrate. To overcome this limitation, multipass laser welding technique using filler wire addition was developed to join thick plate.

The joint geometry is shown in Fig. 14. The focus point was located 36mm below the surface at the first layer and at around the middle of the each deposition height at the following layers using 1.6mm wire. Fig. 15 shows the cross-section of the weld produced with 5 passes at 35cm/min. welding speed showing bead width of approximately 7mm corresponding to an aspect ratio of approximately 7. Gap width at the surface initially 6mm became about 4.5mm at depositing the final layer by shrinkage deformation.

3.6 Arc Augmented Laser Welding

In this technique, additional heat energy is given through tungsten (TIG) arc in augmentation with Laser beam. This additional heat energy enhances the depth of penetration and/or welding speed. It is proved that around 40 to 60% increase in penetration and 100% increase in welding speed can be achieved by adopting this technique. This dual heat source also causes a contraction of the arc root into the Laser generated keyhole and resulting in increased penetration and stable arc even at higher welding speeds.

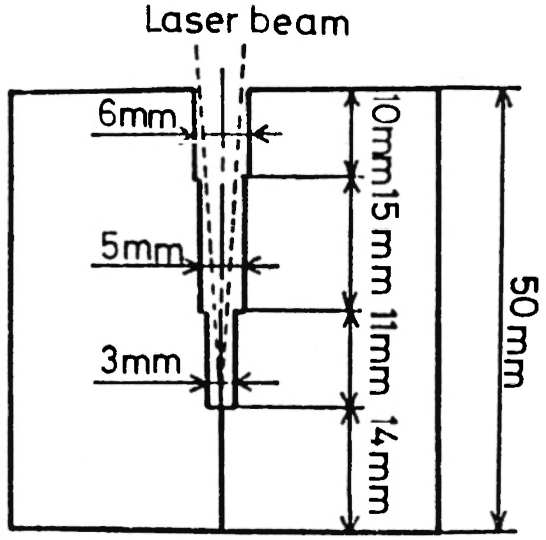


Fig. 14. *Multipass laser welding-joint geometry*

Both processes mutually help each other in enhancing the capacilities under augmentation, but otherwise having limitations as an individual process. For example joint fit-up critical requirements of Laser welding can be overcome by this technique. The disadvantage of this techniques is the increased weld bead width and the distortion.

4. LASER WELDING APPLICATIONS

4.1 Automobile Industry Applications

Laser welding of mass produced automobile parts using powers upto 5 kW is on the increase. The applications range from precision transmission parts to engine parts, body panels and other automobile parts.

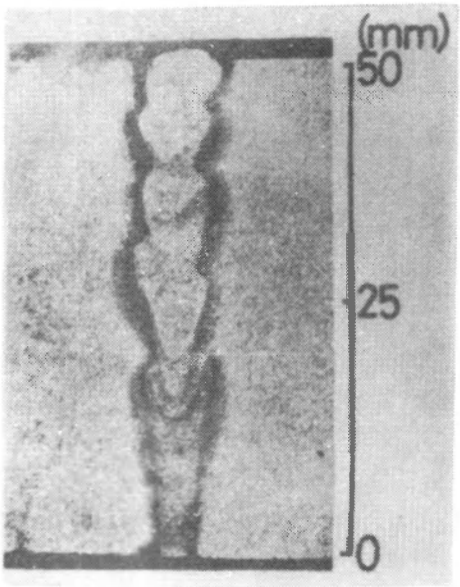


Fig. 15. *Macro view of multipass laser weld*

4.1.1 Engine Parts

The potential applications of Laser welding in engine includes fabricating sumps, bearings, crank cases, connecting rods, ancillary components like alternators and fuel delivery equipment . Mercedes Benz have reported about welding applications which are in mass production on automatic machines. The first is the fabrication of pressed steel hydraulic tappet bearing. They achieved component times of 4 secs (producing 8000 units in 2 shifts).

The second application is in a diesel engine precombustion chamber. The tubular region between two dissimilar parts (x 10 cr 13 and Si 52-2) requires a weld depth of 2.5mm to 3mm. This was achieved by Laser welding Earlier these parts were screwed together. Doing away with thread cutting etc. saved cost substantially; and welding gave a smoother surface to the chamber. this improved combustion and reduced soot content in exhaust. With respect to ancillary engine components fuel filters are being fabricated by Laser welding. A filter is assembled from a can, a cover and two end fittings. This can be done by crimping or welding. Crimping is not very reliable; so welding is done, which is either by TIG or Laser. For this particular application, to get equal production one needs to invest 3 times more for a TIG system when compared to a Laser system. Here the end fittings are first lap welded to cover and can. After the filter material is inserted the cap is pressed on can and lap welded.

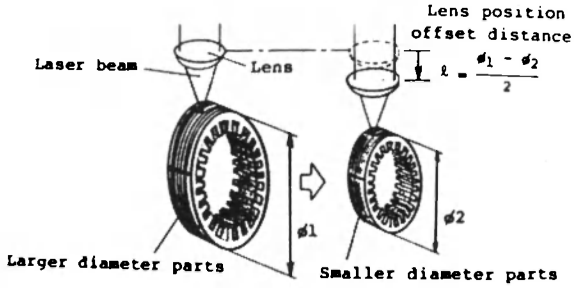


Fig. 16. *Laser welding of core laminations stacking of different sizes in auto parts*

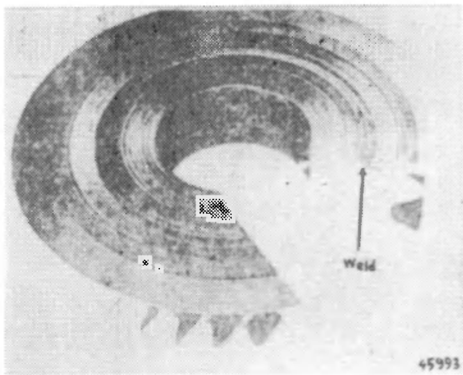


Fig. 17. *Laser welded synchronous gear ring.*

4.1.2 Auto Parts

Among the autoparts, Laser welding is used extensively in startors, motors, dynamos etc. In stator cores, the stator is laminated to reduce eddy current. These laminated sheets were earlier being rivetted. As these parts became more and more compact the cores became smaller, reducing peripheral band width area. First arc and then resistance welding was used. When the peripheral width was reduced to 4mm, the CO_2 Laser was tried. This proved to be a very successful way of welding the laminated core. For varying diameters of cores, one just has to vary the focal point of the beam. So Laser welding gives the required flexibility in manufacturing of auto parts See Fig. 16 & 17.

4.1.3 Transmission Parts

Here majority of applications are for welding premachined precision made parts because beam welding produces deep fusion welds with low disortion, it allows gears to be welded on shafts. This reduces the machining out the entire part. In other words, this property of Laser welding enables parts, that normally difficult or impossible to machine, to be fabri-

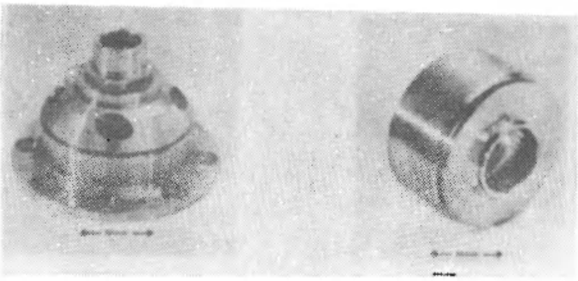


Fig. 18. *Laser welded visco differential and control units*

cated in 2 or 3 parts and then joined together. Another example are the Vasco control units and Vasco differential units (Fig. 18). The butt weld required is done by Laser welding. Both the units have internal splines; and it would be impossible to machine them if they have to be fabricated from a single piece. Laser welding allows for reduction in machining time and material wastage. Laser welding is also being experimented for manufacturing brake shoes, steering columns, clutches, torque convertors, and wheels.

4.1.4 Body Parts

In the last 40 years, welds for mass produced auto body parts have been produced by resistance spot welding and seam welding. Though this is a reliable technique, it necessitates the use of lap joint and also needs electrode to access joint on both sides. This limits opportunity to simplify fabrication and save material. Laser being a high energy density welding technique can make many configurations in sheet metal, like lap, butt, edge, edge fillet, T, flared T joints. This has increased scope for auto body fabrication. Volve has reported trials on B pillars and drip rails. General motors have done study for Laser welding roof to quarter panel ditch joint. Fig.19 shows areas of car body under consideration for Laser welding.

Underbody welding has been successfully implemented with 6kW Laser system by Ford Motor Company. The Laser remains stationary and motion of the freedom by a combination of moving mirrors. The ease with which the beam may be directed with this optical arrangement, coupled with a longitudinal degree of freedom obtained by moving the automotive underbody, facilities welding over the complex contours associated with various humps and ridges of the underbody.

With this system, penetrations of 2.5mm have been

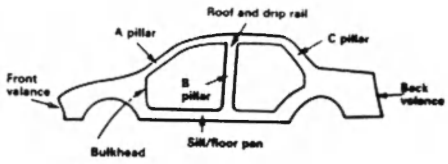


Fig. 19. *Car body construction under consideration for fabrication by laser welding*

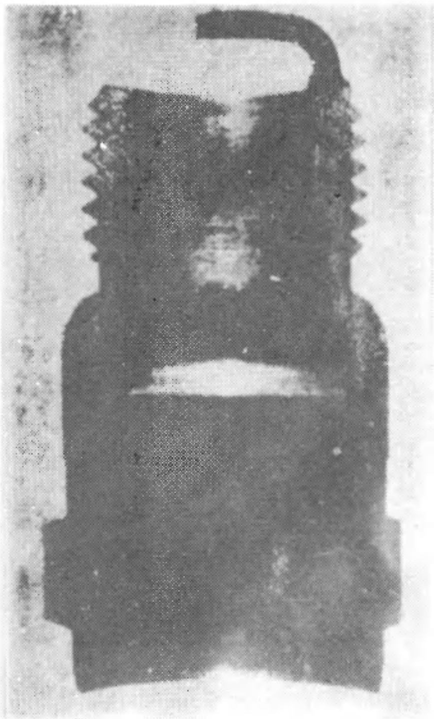


Fig.20. *Nickel electrode laser welded to cold-rolled spark plug body*

achieved at speeds greater than 5m/min and penetrations of 1.5 mm have been achieved at speeds near 12.5 m/min. This welding performance allows upto 60 underbodies to be welded per hour on an assembly line basis. The underbody welding offers striking proof of the ability of the Laser to produce high speed welds in large, complex parts.

4.1.5 Spark Plug

Fig. 20 shows nickel electrode Laser welded to cold-rolled steel spark plug body. In this case, the part had been resistance welded and subsequently rejected because of poor joints; Laser welding was a reclaiming process. A 575 watts beam with using a 2.5" lens (5 millisecond pulse length,100 pulses per second) was used. The weld time was 330 milliseconds and the penetration was 1.5 mm.

4.1.6 Exhaust Gas Oxygen Sensor

The TiO_2 exhaust gas oxygen (EGO) sensor developed by the Ford Motor Company is one of many new products related to emission control systems. The sensing unit provides the air fuel ratio feed back control with a signal proportional to the CO_2 content of the exhaust gases. Ni-Cr lead wires are joined with terminals pins of the sensor in a gas leak tightness by Laser welding. Ni-Cr lead wire was used as the filler metal and a defocussed Laser beam was employed as the heat source in this application, using a 1.5 kW Laser.

4.1.7 Futuristic Trends

Production lin~s are moving continuously towards FMS, and so the Laser processing equipment installed in such production lines must be compatiable with FMS. The Fig-21 shows an example of a laser processing system in FMS. Such a system will use flexible optical systems like fibre optics. This will require

1) Increased stability in high Laser output power
   - Oscillator self-diagonsis function
   - Oscillator self-recovery function
2) Fibre optics system for CO_2 Laser
3) High power Laser equipment which can use fibre optics.

The current fibre optics beam emitting system for YAG Laser have a dia of 30mm. If this can be reduced to the diameter of the optic fibre, freedom in processing will be remarkably increased.. New systems must incorporate in-process monitoring to assure weld quality, sensors to detect defects. If the problems of part fit up and galvanized sheets are overcome large numbers of Laser will replace spot welders. Laser processing is beginning to pay off the investment made to incorporate them. The next decade will make industrial robots common sights on assembly lines. Fig. 22 shows an example of an assembly line with multiple welding heads supplied by a single Laser source. When certain technological problems raised by the transmission of CO_2 Laser beams are resolved, the fields of application will undoubtedly be enlarged.

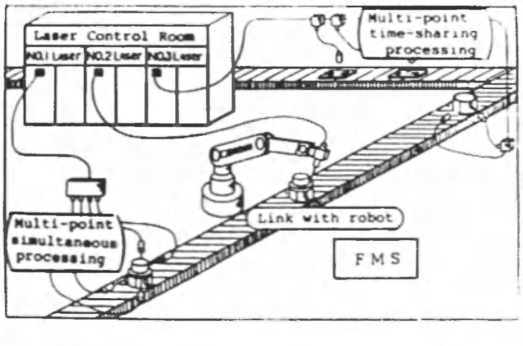


Fig. 21. *Laser processing system in FMS*

4.2 Power Industry Applications

4.2.1 Laser welding in manufacture of gas turbines and steam turbine engine parts

Fundamental and feasibility studies have been done on the application of Laser welding to gas turbine and steam turbines. At present, gas turbine ducts are fabricated with GTA welding. If a Laser process is available for the welding of this component, a large benefit can be derived. Tests showed that stainless steel plate of 8mm thickness can be welded by 5kW CO_2 Laser. By using filler wire at feed rate of 1.5m/min the allowable gap for 6mm thick plate was increased from 0.3mm to 1mm. Conventional steam turbine nozzles diaphrams are manufactured with welding after machining complex shapes or by making nozzle openings by electro-discharging process. The nozzles diaphrams consists of pair of outer and inner rings; spacer rings to which are welded simple shaped nozzle parts. In the new technique, slots are made on spacer rings; and the simple shaped nozzle parts are inserted into these slots and welded. This welding is done by Laser using filler wire. Fig.23 shows the appearance of test piece before and after Laser welding.

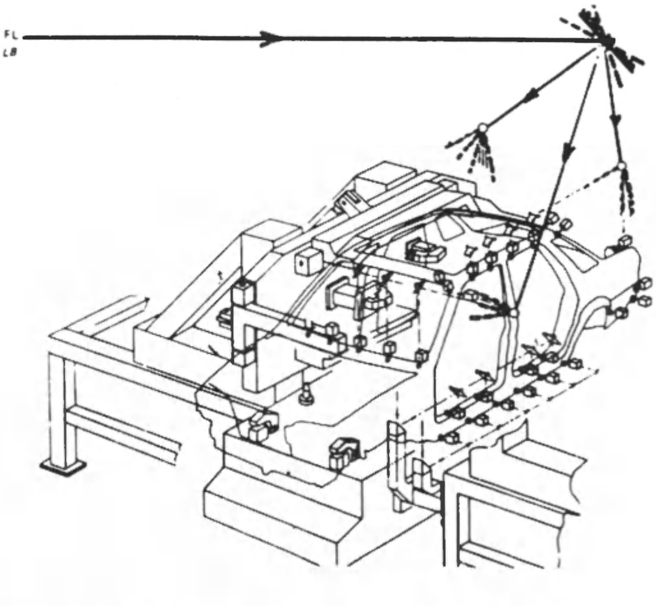


Fig. 22. *Assembly line with one laser source supplying several welding heads*

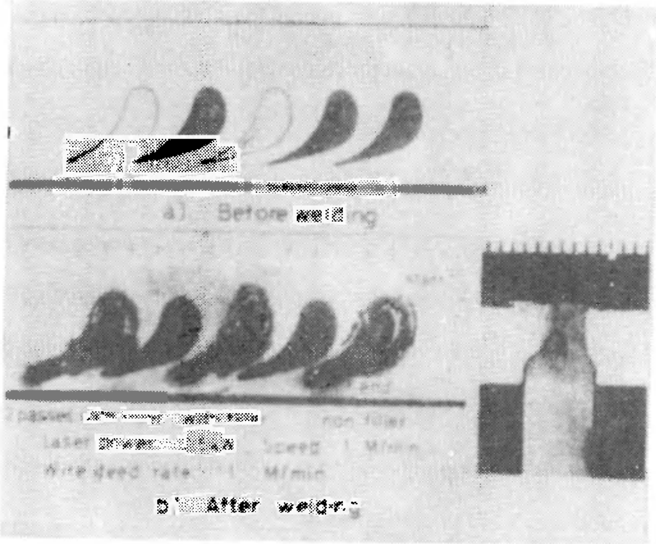


Fig. 23. *Nozzle diaphrams test piece laser welding*

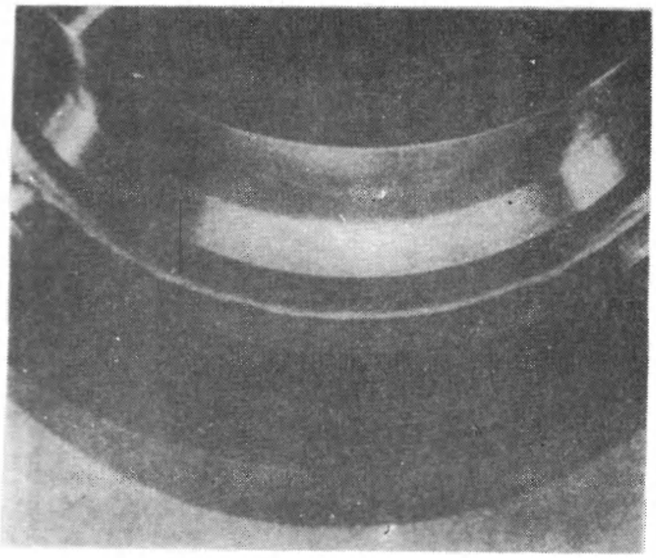


Fig. 24. *Close-up view of laser welded chandelles to the sommier plates of the reactor*

4.2.2 Boiler Membrane Panels

The fabrication of power stations and petro chemical plant involves making a large number of welded joints between pipes, between tube and tube plates, and between tubes and panels, and Laser are being considered for welding each of these. The fabrication of boiler membrane panels has been another area of recent investigation. These panels, used for the walls of spiral furnaces, consists of tubes upto 30 m in length; joined by flat strip. The parts are currently fabricated by sumberged arc welding, which requires welds to be made on both sides of the panels. With the Laser, autogenous welds can be made from one side only, greatly reducing fabrication time, component disortion and the complexity of the work handling system.

4.2.3 Laser Welding of SS Spindle Assembly

As an import substitution for stainless steel spindle assembly of bellow component for BHEL (India), the feasibility welding of the component was taken up at Welding Research Institute. 2 welded lap joints were to be done with dissimilar thicknesses of 0.1 mm to 0.4 mm and 2 more of 1.2 mm to 3.7 mm. Successful circumferential welds conforming to the requirements of partial penetration and steam leak tightness were obtained at welding speed of 425 mm/min. The welds were found to be free from defects.

4.3 Nuclear Applications

4.3.1 Tubes to Grid for the Core

The Nuclear industry has been active in the development of Laser applications for many years because of it allows remote operation for processing in reactive environments. Welding of a very large number of tubes to a grid for the core of the super phoneix 2 nuclear reactor chose to look at Laser and EB welding only, since very close dimensional tolerances on the structure precluded other proceses. While both processes gave similar welding performance. Laser welding was eventually chosen for production, as it could be operated without a vacuum chamber and the Laser beam was easily manipulated around the structure.

4.3.2 Chandelle to the Bearing Plate

The feasibility welding of chandelles to the sommier plates of the super phoneix 2 (SP X 2) reactor has been successfully carried out. Fig. 24 shows the samples Laser welded. The sommier material is AISI 304L stainless steel. 15kW power CO_2 Laser equipment has been employed with operating power parameter of 12 kW. The welding speeds have been kept at 2.7m/min. and 1.2m/min. in order to achieve penetration depths of 8mm and 12mm respectively. It is reported that there is no hardness difference in the weld zone with respect to the base material. The tensile tests demonstrate a higher toughness in the joint than in the base material.

4.3.3 Zircaloy and Stainless Steel Fuel Pins

CNC based Nd-YAG Laser welding system has been employed by Bhaba Atomic Research Centre, Bombay, India for welding fuel rods of zircaloy and stainless steel materials inside the glove box. It is reported that zircaloy welds generally have shown much less colouration compared to GTAW welds made under identical conditions. The heat affected zone was very

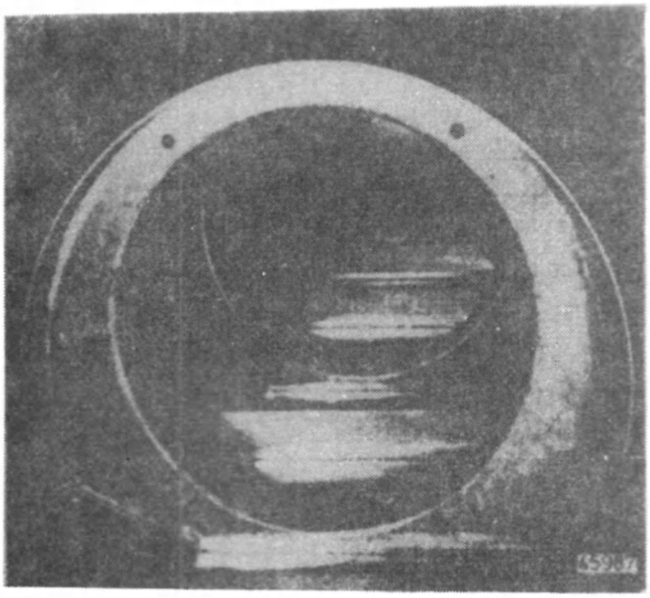


Fig. 25. *Laser welded missile section of 2.5mm thick stainless steel*

narrow because of the higher power density of the pulsed Laser. Micro hardness of these pulsed Laser welds is almost the same as that of the GTAW welds. Accepted welds have been produced by the Laser welding system.

4.4 Aerospace Applications

4.4.1 Gas Turbines

The aerospace industry was quick to take to the idea of Laser welding in the late 1970s (Fig. 25). For example, Pratt and Whitney began production welding 6 mm thick parts for gas turbines using a 6 kW Laser in 1979. The growth in applications for aerospace has not, however, been as rapid as might have been expected and electron beam welding has remained the favoured process in the majority of applications to which power beam welding is applicable. However, there are some production systems installed and there continues to be considerable research activity looking at the production and performance of Laser welds in a wide variety of aerospace alloys. This suggests that growth in the application of Laser in the aerospace industry is likely in the next few years.

4.4.2 Aircraft Panels Stitch Welding

In this application, a corregated section is to be welded between two plates whose separation is 10mm (Fig. 26). Each plate is 1mm thick and the corregated section is 0.8 mm thick. Both are made from a nimonic alloy, which is difficult to weld by other techniques. But using the Laser, high quality welds are produced

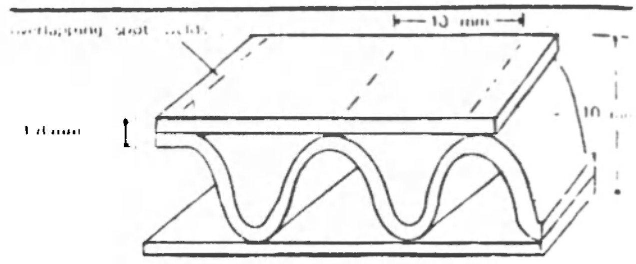


Fig. 26. *Stitch welding of aircraft panels corrugated section*

accurately and repeatedly through two layers of material i.e. through a total weld width of 18 mm.

The dimensions of the panel ar 1mm by 0.5m with weld lines occuring every 10 mm. Of course, seam welding along the entire contact length of the plate and corregation would ensure good weld strength. But the time taken to process each panel by this method would be unacceptably long. So using a Nd-YAG Laser the manufacturer now uses a stitch welding technique to combine strength with rapid processing. A series of 10 overlapping spot welds is carried out at 10mm intervals along each weld line. During each burst of spot welds, the operating speed is 150 mm/min.

4.5 Defence Applications

4.5.1 Recuperators Fabrication

Laser welding is being employed to fabricate recuperators for turbine engines that power army tanks. Laser welding is done to join two air inlet and outlet holes to form a plate pair. The stacked plate pair are then again welded around the outter and inner diameters. Each recuperator has a total weld of of 3000 metres. This method has been adopted mainly due to the distortion free weld properties at Laser welds. The material of the plate is Inconel 625.

4.5.2 Gun Mount Fabrication

Fig. 27 shows the hoist and strike down tubes of the Mark 6 component of the Mark 45 Gun Mount. The hoist and strike down tubes comprise the main structure in the material handling mechanism for loading and unloading ammunition in the Mark 45. The Laser beam welding application is a linear 4.75 mm thick butt weld on the shell to flange. The steels are corten and 1015. The present method is submerged arc welding, requiring two passes. Laser beam welding will require only one pass with no filler wire addition and no backgouge operation. Also, grinding and straightening will be reduced due to the non-contact, low distortion properties of Laser welding. The cost saving of more than $200,000 is being

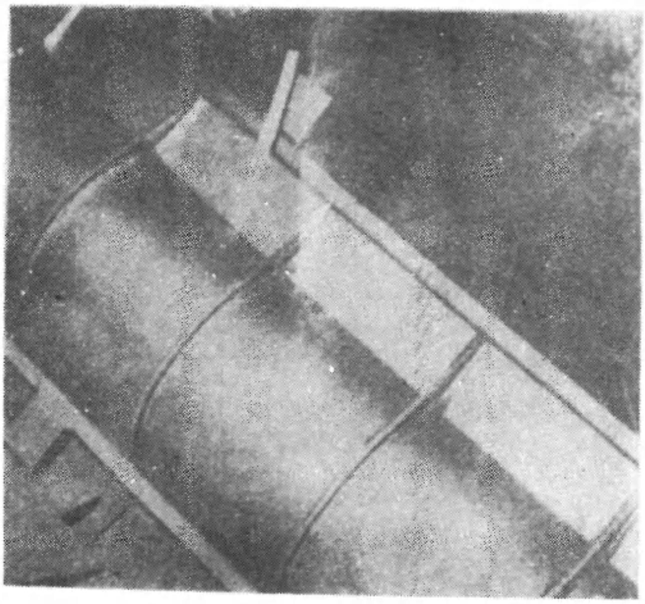


Fig.27. *Laser welded hoist and strikedown tubes of the gun mount*

claimed based on Mark 45 systems per year resulting from Laser beam welding. The cost savings associated with these welds was not associated with the faster welding speed of the Laser beam welder, but rather with the lower heat input and the consequent lower distortion.

4.6 Battery Can and Food Can Applications

4.6.1 Battery Can

Battery cans have been hermetically welded by Lasers. The example shown in Fig. 28 is a 38 mm diameter nickel plated, cold-rolled steel can with the top welded on around 1 mm lip. A 375 watt beam (with a 2.5" lens) in a pulsed mode (80 pulses per second, 4 millisecond pulse length) was used to achieve 0.75 mm penetration. The weld time was 8 seconds per can.

The similar application of battery can hermetic seal welding was carried out at Welding Research Institute, BHEL, India (48). The most critical requirement of this application was that during welding there should be no thermal damage to the non-woven nylon seperator, which is kept as a roll inside the can for the insulation purpose between positive and negative electrodes. Though the nylon roll was almost occupying the entire volume of the can, there was absolutely no thermal damage to the seperator after the successfully hermetic welding between the can and the lid. CO_2 Laser equipment of 600 watts capacity was used for this application in continuous wave (CW) mode operation.

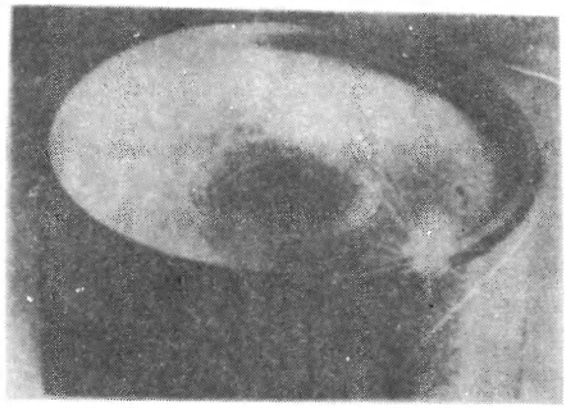


Fig. 28. *Laser welding of nickel-plated steel battery can*

4.6.2 Food & Aerosol Cans

Laser side seam welding was developed as an alternative to soldering or resistance welding for food and aerosol cans manufacture. This eliminated lead and its associated health hazard to the consumer and the machine operator. Also, eliminated copper wire used in the resistance seam welding process. It resulted in improved efficiency by the use of a non-contact electrodeless welding procedure. These cans were made from 0.2 mm thick tin plate. Laser welding went on line in multiple shift operation in 1983. An ultra reliable new CO_2 Laser was designed and built specifically for this purpose suiting to the demand of this application. Welding speeds of 30m/min. at 800 watts power is being reported.

4.7 Electrical and Electronics Applications

4.7.1 Micro Motor Coil

Unit now motor coils have been produced by winding a round wire continuously. But now an entirely new system has been developed to make a motor coil without winding wires, by utilising a pulsed Nd-YAG Laser. This new development results in the production of coil with extremely high space factor, capable of manufacturing a small size servo motor of high efficiency and excellent controllability.

A pulsed Nd-YAG Laser is used to make high reliability butt welds at high speed. Joining of Cu or Al wires for coil forms a key technology in the manufacturing process of the high density armature coil. Fig. 29 shows schematically new manufacturing process of the armature of the commercialised and miniaturised DC coreless servo motor.

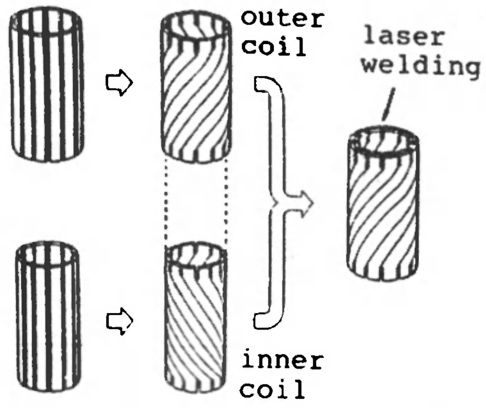
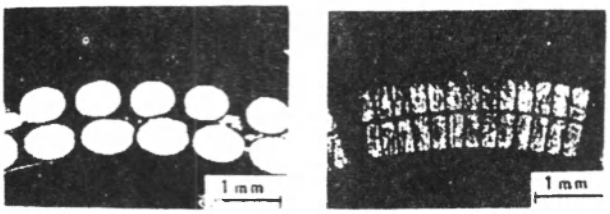


Fig. 1 Production method of armature coil without winding wires.



(a) Conventional coil (b) Newly developed coil

Fig. 29. *Cross section of micro motor coil*

4.7.2 Laser in Lamp Making

In the modern European automobile dual filament headlamps, the 'passing beam' filament is mounted within a tiny shield, which is welded to the lamp frame on which both filaments are mounted. Mechanical shocs and vibrations during service call for very strong welded joint. Earlier methods adopted resistance welding of 0.25mm thick molybdenum shield to the molybdenum frame. Component distortion and local crystallisation occured as a result of resistance welding. Since pulsed laser provides highly localised and short energy incidence times, crystallisation effects can be greatly reduced. YAG 'Laser is being used by Thorn Lighting Ltd.,UK. Production rate of 1650 assemblies per hour are routinely achieved on their systems, which has been in daily use for 10 years.

The same company has incorporated a 800 YAG Laser in their welding system,which was designed to process a range of lamp frame assemblies. The ceramic discharge tubes used in high pressure sodium lamps are mounted on simple SS wire frames within an evacuated glass envelope. Earlier method of resistance welding was replaced by pulsed Laser. The focused spot was moved across the junction of the wires forming the stitched weld. Single short pulsed are then directed at the niobium-stainless steel joints at each end of the discharge tube. Pulse repetition tes of 5 per second with energy of 13 J/pulse were used for stitch welds 2. pulses of 13 j were used for niobium-stainless steel joints.

4.7.3 Relays Manufacture and Other Applications

The laser has been accomplised for welding of small electrical relay cans to effect a hermetic seal without degradation of the glass to metal seals at the base of the contact pins, because of negligible heat diffusion into the enclosure (Fig. 30). For this reason, tiny pacemaker cans and integrated circuit (IC) packs are Laser welded. Some Laser welders are equipped with a microscope for viewing and aiming. Miniaturized electronic components, time piece and camera parts and instrument parts, which require a precisely controlled weld and consistency registration lend themselves to Laser welding. A 3 kW system is being integrated into a production welding system for lead-acid storage batteries.

Of greater interest is the Laser sealing of large metal electronic packages. These are currently welded satisfactorily at very high rates. (1 package/sec.) by automatic 'single-shot' resistance projection welding, but weld quality becomes an increasing problem as package exceed 25 mm in diameter. Small scale

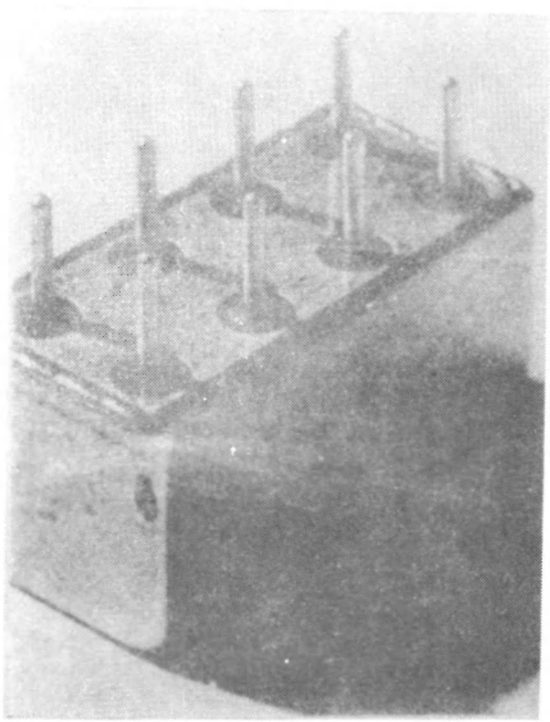


Fig. 30. *Hermetic seal welding of electrical relay can*

resistance seam welding machines have been developed for such larger packages but the welding rate is slow (0.1m/min.), electrode wear is rapid and doubts exist as to the weld quality, especially at package corners. Since packages are required to contain a dry nitrogen atmosphere, EB welding is not attractive and neither is soldering because of the difficulty of ensuring flux removal. Both solid state and CO_2 Lasers have been considered for this application, for the former being capable of welding at speed of approximately 0.5m/min. and the latter approximately at 3m/min.

Another application of pulsed Laser welding was the recuperation of defective image display tubes in which an open weld may be missed during manufacture. Under normal conditions, since the tube was already sealed,the defective product would have been scrapped. But since glass is transparent to certain wavelengths of Laser, pulsed Laser was utilised for closing the open welds without disturbing the assembly.

4.7.4 Heart Pacemaker Manufacture

Heart pacemakers are implanted for the patients suffering from arrhythmic heart disease. As electrical simulation of the heart became accepted, a new industry centred upon microelectronics. About one third of a millon pacemakers are implanted annually and continuing technological advance will ensure that this number continues to increase.

Laser welding has become a key process in the manufacture of pacemakers, and had advantages compared to EB welding and TIG welding. The pacemaker is made of titanium material. Pulsed YAG Laser was employed for the application with pulse length of 7m.sec. and pulse energy of 8J maximum at 5Hz repetition rate.

4.8 Ship-building Applications

A 15 kW Laser welding machine has effectively replaced the conventional submerged arc welding process. The advantages offered by the Laser system are increased welding speed, lower distortion and other thermal effects,reduction of filler material consumption and last but not the least of all single pass welds instead of seven pass submereged arc welds.

Six types of Laser beam welded joints are currently being investigated for production applications at Northern Ordinance (USA). Viz. square butt plate joints, melt through corner joints and melt through seam joints. In one application, Laser is used to weld 'ready service ring' rails for guided missile launch system. This involves welding butt joints (22 mm thick) of carbon steel plates. Shell to flange butt joints on the tubes were Laser welded. There are few production applications for Laser welding in ship building at present, particularly in the area of panel welding. Panel welding by Laser could either involve through thickness welding of solid panels, with or without the use of filler wire, or the production of light weight structural panels. These panels are welded at a Laser power of 10 kW and a welding speed of 5m/min.

In the study of the applicability of Laser welding to merchant ship construction, grade A,B and C ship steels were welded in thickness ranging from 9.5mm to 12.7 mm for grade A, 12.7mm to 19.0 mm for grade B, 25.4 mm to 28.6 mm for grade C. Welding was accomplished with a Cw, continuously cooled, high power CO_2 at power levels from 5.5 to 12.8 kW. At these power levels, it was necessary to weld the 19.0mm and 25.4mm thick materials in two passes, one from each side. The welding of the tee section was accomplished by impinging the Laser beam of the seam at a low angle of incidence (6 to 9 degrees) to the plate.

5. CONCLUDING REMARKS

Due to high flexibility of Laser beam, as per latest developments, 10kW orbital Laser welding system (Fig. 31) has been used to demonstrate the autogenous butt welding of 18 mm thick, 0.76 m diameter pipeline in a single pass welding lasting only seven to eight minutes (57). 5kW welding has been carried out at distances exceeding 75 m from the Laser. Laser welding of pipe from inside has been carried out by passing the beam through a mirror, which could be rotated inside the pipe to move the beam around the joint (Fig.32). Pilot trials have been made using a 10 kW Laser to weld a 300mm diameter stainless steel pipe with a wall thickness of 8.5 at a speed of 1.8 m/min. i.e. 35 seconds to complete the joint (58). These demonstrations have proved, beyond doubt, that LBW is more flexible for various applications when compared to competitive EBW process.

The success of the industrial Laser applications will undoubtedly contribute to rapid expansion of the industrial use of Laser welding. The unparalleled adaptability of the Laser process to automation will be a higher factor in speeding its acceptance by industry.

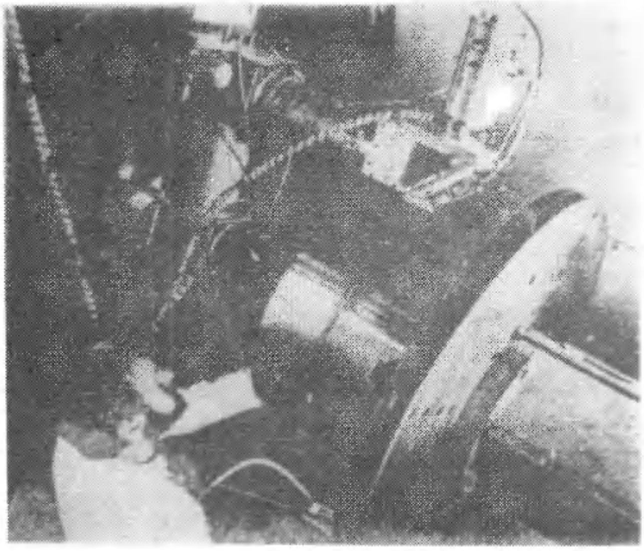


Fig. 31. *10kw Orbital laser welding system*

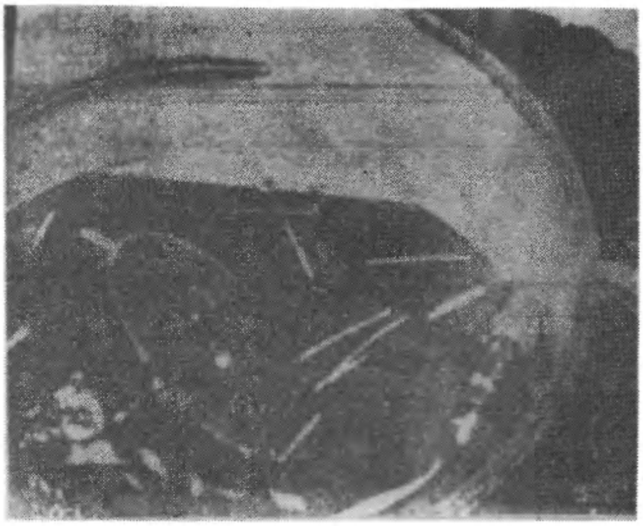


Fig. 32. *Laser welding of pipe from inside with a rotating mirror*

Back to the Basic — GMA Welding Process

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Pulsed operation produces spray transfer at much lower average currents than those required for the normal spray transition. The droplets are transferred during the high current pulse (ideally one drop per pulse) while a low background current maintains the arc between the pulses, as shown in fig 5 . Excellent arc stability and negligible spatter levels are produced with this type of transfer.

Dip Transfer

In dip transfer the arcing current is insufficient to melt the filler wire as it feeds towards the plate. The arc gap gradually decreases and the wire dips into the weld pool, causing a short circuit to occur. The current rises rapidly and the short circuit ruptures to detach some of the filler wire and re-establish the arc.

This sequence of events is repeated in a relatively regular manner as shown in fig 6, (at frequencies of 100 to 200 H_z). The low current and the addition of relatively coldwire ensure a low heat input and limit the size of the weld pool. For these reasons the dip transfer mode is suitable for positional work and the joining of thin sheet material. The high current surge prior to rupture of the short circuit may give rise to spatter but this may be controlled by the selection of the correct shielding gas and adjustment of the operating parameters.

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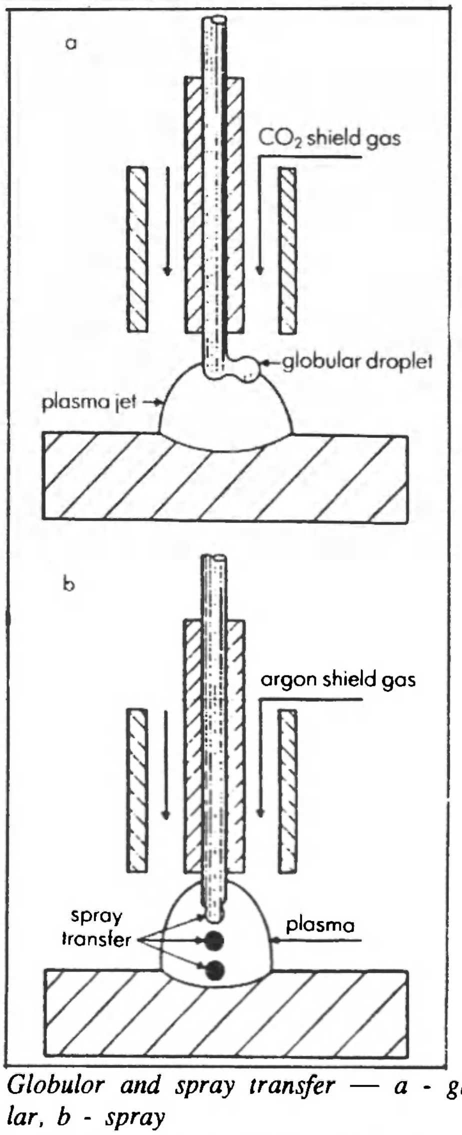

Fig. 4. *Globulor and spray transfer — a - globular, b - spray*