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Laser Beams A Novel Tool for Welding: A Review

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Abstract: *Welding is an important joining process of industrial fabrication and manufacturing. This review article briefs the materials processing and welding by laser beam with its special characteristics nature. Laser augmented welding process offers main atvantages such as autogenous welding, welding of high thickness, dissimilar welding, hybrid laser welding, optical fibre delivery, remote laser welding, eco-friendly, variety of sources and their wide range of applications are highlighted. Significance of Nd: YAG laser welding and pulsed wave over continuous wave pattern on laser material processesare discussed. Influence of operating parameter of the laser beam for the welding process are briefed including optical fibre delivery and shielding gas during laser welding. Some insight gained in the study of optimization techniques of laser welding parameters to achieve good weld bead geometry and mechanical properties. Significance of laser welding on stainless steels and other materials such as Aluminium, Titanium, Magnesium, copper, etc…are discussed.*

I. INTRODUCTION

Welding is the principal industrial process used for joining metals. As materials continue to be highly engineered in terms of metallic and metallurgical continuity, structural integrity and microstructure, hence, welding processes will become more important and more prominent. Now a days, laser materials processing has received much attention than traditional techniques due to its controlled transfer of clean energy, enhanced design flexibility of laser sources permits to perform various technological operations with same laser system noticeably; delivering the laser beam through an optical fiber system leads the welding to the new era, since welding can be performed in all possible positions even though the weld location is so difficult. In addition, it allows robotic linkages, reduced man-power, full automation and systematization. The theoretical and experimental study of laser welding began in 1962, Since then, the use of laser welding has grown swiftly, as the new manufacturing possibilities became better understood (Sabbaghzadeh Jamshed). Now days, laser is finding growing acceptance in field of manufacturing as cost of lasers has decreased and capabilities are having increased.

Laser Materials Processing And Laser Welding

Due to its special characteristics (Having high mono chromaticity, coherence, directionality and intensity), laser beam discovers many applications in the field of metallurgy compared with other forms of material processes(E.P.Velikhov). The focused laser beam is one of the highest power density sources available to industry similar in power density to an electron beam. But, unlike electron beam, laser beam required no vacuum space to use. Moreover, any technological action of Laser Beam processing represents a controlled transfer of energy, conditioned and intermediated by laser beam incidence and respectively, absorbance on the work piece surface.Adelina Han et al represents a group of technological processing methods by laser beam such as heat treatment, welding, removal of the material, alloying, cladding, cutting and drilling are shown in figure1(Adelina Han).

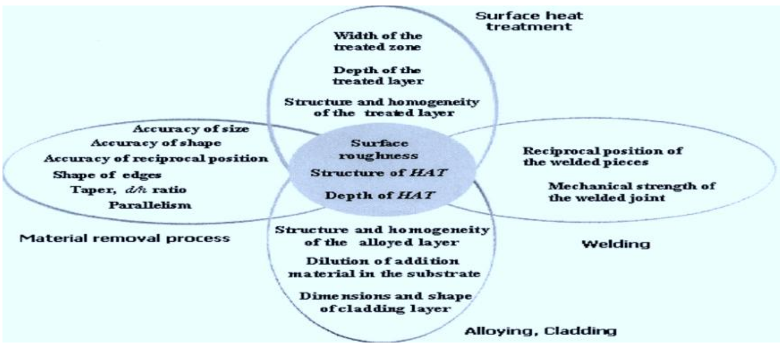


Figure 0: Objective functions of the laser assisted material processing

Laser Augmented Welding Process

Welding is an important machining process of industrial fabrication and manufacturing. But, few of the important problems occurs during conventional machining process that are cracks, inclusions, incomplete fusion of the base and weld metal, incomplete penetration, unacceptable weld shape, arc strikes, spatter, undesirable metallurgical changes, excessive distortion and thermally induced stresses etc…must be minimized by proper consideration of the characteristics and requirements of the process.Laser beam welding addressing these issues with added advantages such as low heat input, small heat affected zone, elimination of flux (autogenous welding), low weld distortion, high welding velocity**,** absence of mechanically induced material damage and of tool wear, greater resistance to vibration and shock, minimum degradation of heat sensitive components during assembly, increased reliability, single pass thick section capability etc….

On the other side, the ecological welding processes must comply with the technical requirements for the environmental protection and occupational health, according to the ISO 9000, ISO 14001 and ISO 18001 standards (V.Verbitchi). But, conventional methods such as the gas metal arc welding process (GMAW), Shielded metal arc welding (SMAW), Flux cored arc welding (FCAW), submerged arc welding (SAW) are emitting gaseous pollutants (including "greenhouse" gases) include carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x), and ozone (O_3) and fumes include manganese (Mg), nickel (Ni), chromium (Cr), cobalt (Co), and lead (Pb) oxides (R.M.Evans). Due to rapid rise of welding industry, the amount of particle of gaseous pollutants increases those are small enough to remain airborne and be easily inhaled. However, these could be dangerous to environment and hazardous to the welder's health.

In order to reduce the fuel consumption and release of CO_2 gas for protecting the environment more and more high performance materials have been developed. In manufacturing of high performance materials such as stainless steels, composite materials, ultra-high strength steels, titanium alloys, magnesium alloys and high wear-resistance coating etc… their compatibility of welding methods also be considered ecologically. Electron Beam welding, Friction stir welding and Ultrasonic welding are ecological, because their emission level is almost zero, as the operation principles were contrived. Laser welding also considered an ecological process, as its emission level is very low, due to the efficient filtering systems applied by the modern welding equipment of this class (I. Pires).

Enhanced design flexibility of laser sources permits to perform various technological operations with same laser system noticeably; delivering the laser beam through an optical fiber system leads the welding to the new era, since welding can be performed in all possible positions even though the weld location is so difficult. In addition, it allows robotic linkages, reduced man-power, full automation and systematization. The theoretical and experimental study of laser welding began in 1970's. Since then, the use of laser welding has grown swiftly, as the new manufacturing possibilities became better understood. Now days, laser is finding growing acceptance in field of manufacturing as cost of lasers has decreased and capabilities are having increased(K.SureshKumar).

Advantages Of Laser Welding

The laser welding offers many features which make it an attractive alternative to conventional processes (NasirAhmed).

Autogenous Welding: One of the many features of laser welding is the capability to weld without filler material (autogenous welding) (J. Tusek). It has described that the grooves are very precisely made for the parts to be welded must be accurately positioned and secured during welding. Otherwise, unacceptable seam qualities will be produced due to unwanted factors like offset edges, imprecise edge preparation, a joint gap or offset beam occurs during process(Schinzel.C). Laser welding offer non-contact autogenous process that is not affected electrical conductivity or magnetic property of the material being welded. In automobile industry replaces the electro slag welding and other different gas shielded welding by laser beam due to its prominent strong points (Qiang Wu). According to the rule of thumb, an air gap of 10% of plate thickness is allowed in laser welding without filler material. This is a quit tight demand, especially when welding the large structures of joint manufacturing and also fixtures (Tommi). The advantages of an autogenous laser welding over other processes include elimination of flux; narrow width and deep penetration; single pass with high weld speed; higher mechanical strength; greater resistance to vibration and shock; and minimum degradation of heat sensitive components during assembly, and increased reliability(Xiu-Bo Liu). However, filler material may be used to weld wherever tolerance on the joint gap, fit up requirements for many demanding industrial applications(Z. Sun).

Welding Of High Thickness: It has reported that the penetration is tied down to the power of the laser used, according to that, weld penetration is used for single pass welding through the whole thickness by the autogenous way up to 50 mm with exceptionally high power lasers, the common thickness range is up to 20 mm, which laser power up to 20 kW(W.M.Steen). On the other hand, a study explained that laser welding with filler wire procedure along a multi pass welding technique; there is no limitation in weldable thickness, in principle, (Arata.Y.). But, practically, laser power levels are limited for the material thickness involved (Xiu-Bo Liu).Some point of merits of the laser welding with other welding processing are commented in table 1.

Table 1: The main characteristics of laser welding(William M. Steen)**.**

CHARACTERISTICS	COMMENT
High energy density – keyhole type welding	Less distortion
High processing speed	Cost-effective (if fully employed)
Rapid start/stop	Unlike arc processes
Welds at atmospheric pressure	Unlike electron beam welding
No X-rays generated	Unlike electron beam
No filler required (autogenous weld)	No flux cleaning
Narrow weld	Less distortion
Relatively little HAZ	Can weld near heat-sensitive materials
Very accurate welding possible	Can weld thin to thick materials
Good weld bead profile	No clean-up necessary
No beam wander in magnetic field	Unlike electron beam
Little or no contamination	Depends only on gas shrouding
Relatively little evaporation loss of volatile components	Advantages with Mg and Li alloys
Difficult materials can sometimes be welded	General advantage
Relatively easy to automate	General feature of laser processing
Laser can be time-shared	General feature of laser processing

Dissimilar Welding: Joining dissimilar materials became inevitable in engineering industries for both technical and economic reasons. Therefore, continuous efforts are made to apply the dissimilar-metal combinations, despite the many difficulties encountered including problems associated with metallurgical incompatibility(A. K SureshKumar). There are several choices amongst the conventional welding methods, such as, common conventional shielded metal arc, gas tungsten arc, gas metal arc, and submerged arc welding including high energy density sources such as plasma arc and electron beam welding. Apart from these fusion welding methods, solid-state welding methods such as pressure welding, friction, resistance and as well as brazing, soldering, adhesive bonding and mechanical joining can eliminate the fusion problems because the base metals remain in the solid state during joining. However, the service conditions may make particular processes unsuitable, e.g., in high-temperature applications, soldering and adhesive bonding cannot produce the acceptable joint with required geometry and reasonably time consuming. Therefore, solutions relying on high energy density processes such as electron beam welding (EBW) and laser beam welding (LBW), are still of great industrial interest(R Karppi).

Nevertheless, some good results have recently been obtained in laser lap-joint or lap and butt joint one-pass welding of dissimilar materials such as aluminum alloy and steel(T.A.Mai), Steel-Kovar, copper steel and copper-Aluminium without filler materials using 350 W pulsed Nd: YAG source, controlled melting, defect and intermetallic phases free welding obtained shown in figure 2. Laser beam welding of dissimilar joints of Aluminum to steel was prepared and investigated (Alexandre Mathieu). The dissimilar combinations of 2 mm thick 316 L stainless steel and mild steel joints made using pulsed Nd: YAG laser welding(A. J. K Suresh Kumar).

The welding of dissimilar metals is only possible for certain combinations as shown in table 2.(PennWellBooks) Very less work has been reported on laser welding of dissimilar materials combinations especially by the autogenous way.

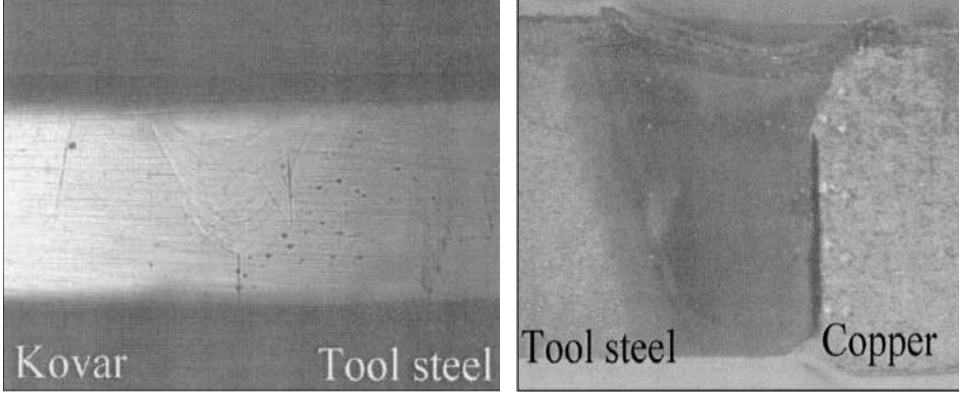


Figure 2: Dissimilar laser welding of Kovar- tool steel, tool steel- copper (T.A.Mai).

Table 2: Metal compatibility for dissimilar welding using lasers (Penn well books, 1990).

	W	Ta	Mo	Cr	Co	Ti	Be	Fe	Pt	Ni	Pd	Cu	Au	Ag	Mg	Al	Zn	Cd	Pb	Sn
W																				
Ta	■																			
Mo	■	■																		
Cr	■	P	■																	
Co	F	P	F	G																
Ti	F	■	■	G	F															
Be	P	P	P	P	F	P														
Fe	F	F	G	■	■	F	F													
Pt	G	F	G	G	■	F	P	G												
Ni	F	G	F	G	■	F	F	G	■											
Pd	F	G	G	G	■	F	F	G	■	■										
Cu	P	P	P	P	F	F	F	F	■	■	■									
Au	–	–	P	F	P	F	F	F	■	■	■	■								
Ag	P	P	P	P	P	F	P	P	F	P	■	F	■							
Mg	P	–	P	P	P	P	P	P	P	P	P	F	F	F						
Al	P	P	P	P	F	F	P	F	P	F	P	F	F	F	F					
Zn	P	–	P	P	F	P	P	F	P	F	F	G	F	G	P	F				
Cd	–	–	–	P	P	P	–	P	F	F	F	P	F	G	■	P	P			
Pb	P	–	P	P	P	P	–	P	P	P	P	P	P	P	P	P	P	P		
Sn	P	P	P	P	P	P	P	P	F	P	F	P	F	F	P	P	P	P	F	

■	Excellent
G	Good
F	Fair
P	Poor

Hybrid Laser Welding: Hybrid Arc-LASER welding technology has been thoroughly studied and successfully applied in the last few years for instance, LASER ND: YAG-GTAW, LASER(A.M.Chelladurai), Nd: YAG–GMAW, LASER CO_2–GMAW (G.Tani) and LASER-MIG (G.Casalino) combinations. Schematic diagram of the experimental set-up of hybrid welding of laser-MIG is shown in figure 3**.** In particular hybrid LASER Nd: YAG–GMAW process meets the needs of automotive industry thanks to its easy implement ability on anthropomorphic robots, while LASER CO_2–GMAW is suitable for shipbuilding industry, but also for transport and aerospace industry applied to panels manufacturing, thanks to its characteristic high powers. On the other side the two welding sources, coupled to perform an hybrid welding process, require a fine tuning of both sets of technological parameters in order to obtain a stable, repeatable and productive process.

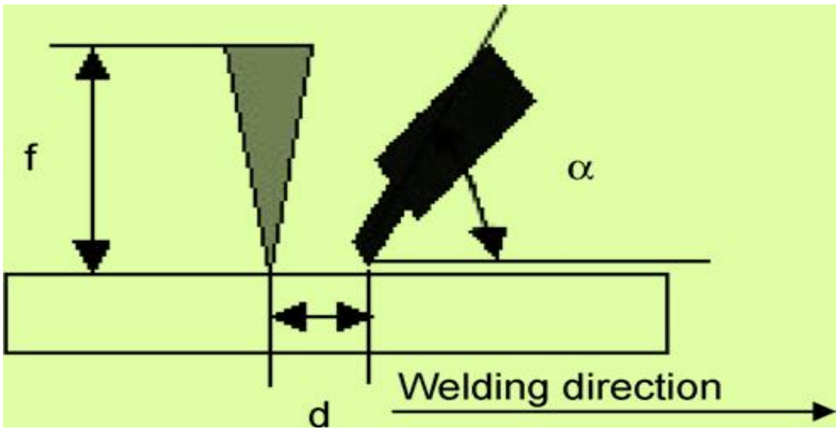


Figure 3: The laser focal distance (f) from the piece surface and the torch angle (α) of LASER-MIG set-up for hybrid welding (G Casalino).

Optical Fibre Delivery: The beam can be delivered flexible via an optical fiber almost without loss which leads to the introduction of remote laser welding. Some laser beam also transferred through an optical mirror system for welding(G.Nath).

Remote Laser Welding (Rlw): The recent developments in laser welding leads to the introduction of remote laser welding (RLW) which uses large focal optics, high power laser sources and mirrors to translate the laser beam in to 3D working volume at high speeds(G.Michalos). Remote welding requires only one side access to the past, allows the minimization of time between welds and it consequently, results in shorter cycle times. The new remote technologies have involved a lot of innovations concerning the peripheral system technologies like scanner system (or) robot path planning. The remote laser technologies with highly brilliant beam sources comprises welding and cutting in a system(M.F.Zaeh).

Eco-Friendly: Conventional methods such as the gas metal arc welding process (GMAW), Shielded metal arc welding (SMAW), Flux cored arc welding (FCAW), submerged arc welding (SAW) are emitting gaseous pollutants as discussed.The ecological footprint of lasers beam welding over plasma arc welding and TIG welding was compared to reveal the importance of laser beam welding to the manufactures about energy consumption, material consumption , hazards , post processing and risk potentials(Martin Dahmen).

Variety Of Sources: During last decades, laser welding has shown incontrovertibly its effectiveness and advantages over traditional welding methods in many studies and also in industrial applications. The main lasers used in material processing are carbon dioxide (CO_2), carbon monoxide (CO), neodymium-doped yttrium aluminium garnet (YAG; Nd:YAG), neodymium glass (Nd: glass), ytterbium-doped YAG (Yb: YAG), erbium-doped YAG (Er: YAG), excimer (KrF, ArF, XeCl) and diode (GaAs, GaAlAs, InGaAs, GaN and others being developed) lasers (William M. Steen). Characteristics, laser media, maximum/normal powers and merits of some typical lasers for welding are given in table 3.

CO_2 laser (wavelength: 10.6 μm; far-infrared ray)		
Laser media	:	CO_2–N_2–He mixed gas (gas)
Average power [CW]	:	45 kW (maximum) (Normal) 500 W – 10 kW
Merit	:	Easier high power (efficiency: 10–20%)
Lamp-pumped YAG laser (wavelength: 1.06 μm; near-infrared ray)		
Laser media	:	Nd^{3+}: $Y_3Al_5O_{12}$ garnet (solid)
Average power [CW]	:	10 kW (cascade type max & fiber-coupling max) (Normal) 50 W–4 kW (efficiency: 1–4%)
Merits	:	Fiber-delivery, and easier handling
Laser Diode (LD) (wavelength: 0.8–0.95 μm; near-infrared ray)		
Laser media	:	InGaAsP, etc. (solid)
Average power [CW]	:	10 kW (stack type max.), 5 kW (fiber-delivery max.)
Merits	:	Compact, and high efficiency (20–50%)
LD-pumped solid-state laser (wavelength: about 1 μm; near-infrared ray)		
Laser media	:	Nd^{3+} : $Y_3Al_5O_{12}$ garnet (solid), etc.
Average power [CW]	:	13.5 kW (fiber-coupling max.)
[PW]	:	6 kW (slab type max.)
Merits	:	Fiber-delivery, high brightness, and high efficiency (10–20%)
Disk laser (wavelength: 1.03 μm; near-infrared ray)		
Laser media	:	Yb^{3+} : YAG or YVO_4 (solid), etc.
Average power [CW]	:	6 kW (cascade type max.)
Merits	:	Fiber-delivery, high brightness, high efficiency (10–15%)
Fiber laser (wavelength: 1.07 μm; near-infrared ray)		
Laser media	:	Yb^{3+} : SiO_2 (solid), etc.
Average power [CW]	:	20 kW (fiber-coupling max.)
Merits	:	Fiber-delivery, high brightness, high efficiency (10–25%)

Table 3: Characteristics and merits of typical lasers for welding (NasirAhmed).

Wide Range Of Applications: Laser welding will became an important joining technique for high strength steels, Zn-coated steels, aluminium alloys, stainless steels, Ni-base super alloys and magnesium alloys and can promote their wider uses in aerospace, aircraft, automotive, electronics, petroleum refinement stations, power plants, ship building, chemical containers, pharmaceutical industry and other Industries (X. Cao). For some extends lasers forming has promising applications in rapid prototyping and shape correction in the aerospace, marine and automobiles sectors (Hong Shen).

Laser welding enables accurate deposition of metals and the subsequent milling increases the surface quality and accuracy to machining standard (Doo-Sun Choi). It is without a doubt that stainless steels are an important class of alloys from low end applications like cooking utensils and furniture to very sophisticated ones such as nuclear power plant and space vehicles.

Significance Of Nd: Yag Laser Welding

Thecomparison of CO_2 laser, Nd: YAG laser and Diode laser which are three important sources to the welding process,among these, diode lasers are generally used for micro welding on thin materials, thin films and IC fabrications. But, CO_2 lasers and Nd: YAG lasers are mainly used in industry to weld hard materials with high thickness due to their higher output power.The biggest difference between CO_2 and an Nd: YAG laser is wavelength of output beams,while its 10.6 µm in case of a CO_2 laser, Nd: YAG laser beam has a wave length of 1.06 µm(Norikazu Tabata)is shows a vast difference in absorption of the laser to the material as shown in figure 4.

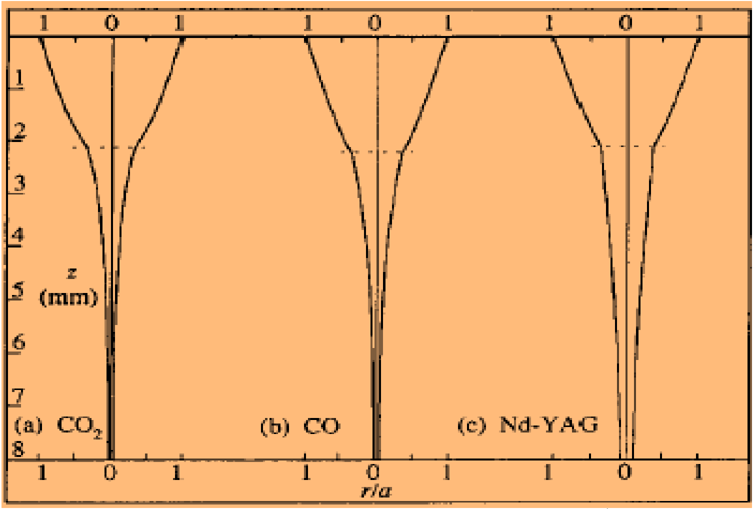


Figure 4: The different profiles obtained for a 4 kW beam at a speed of 25 mm s^{-1} and a focal spot radius of 0.3 mm at the frequencies of (a) a CO_2 laser, (b) a CO laser and (c) a Nd-YAG laser. Broken horizontal lines show where the keyhole radius is one third of its value at the surface(John Dowdon)**.**

Generally, an ideal fiber optic delivery should have efficiency as near to 100% as possible and low output divergence, should be flexible and applicable over as broad a wavelength spectrum as possible, should not be subject to damage by the laser power. In the case of an Nd: YAG laser, the beam can be delivered flexible via an optical fiber almost without loss, while transfer of a CO_2 laser beam is being handled through an optical mirror system. It was reported that during several hours of continuous use of laser delivered by Nd: YAG laser, no attenuation of transmission efficiency was observed in the fiber(G.Nath).In another report pointed out the other advantage of the shorter wavelength of Nd: YAG laser is that it is less sensitive to plasma produced by vaporization of material(José Greses) and (Xiu-Bo Liu). This allows deeper penetration and the process does not need carefully made gas injection as for welding with a CO_2 laser. The other important of Nd-YAG lasers are, rigid and compact oscillator, low reflectivity to cu, Al and their alloys.Among different types of lasers, CO_2 laser has high average beam power and good beam quality, which is suitable for high speed metal cutting(Avanish Kumar Dubey). However, Nd: YAG laser can be operated in pulsed mode with high peak powers enable to process thick materials. Shorter wavelength (1.064 µm) can be absorbed by high reflective materials which is difficult for CO_2 laser.

(M.W Turner) and (M.W Turne)havenoticed that Nd: YAG laser shows direct heating of the containment whereas CO_2 laser by heat conduction into the contaminant during surface cleaning of Ti alloys. Similarly,(M.Schellhorn) and (X. Cao) have reported that CO_2 and Nd: YAGhas been used for laser welding of Mg alloys with recent development of high output power the important of beam quality and possibility of glass fibre delivery.A uniform excitation of the YAG rod and uniform heat dissipation by uniform cooling and compensation of birefringence by inserting a quartz rotator between the Nd: YAG rods are effective techniques for preventing the optical distortion.

Also, Nd:YAG laser beam joining technology offers to manufacture joints of all light metals and their combinations, allowing a weight reduction accompanied by high production efficiency and improved performance in use with cost effective than CO_2 and other methods(A.Ribolla). Among other lasers, increasing welding process efficiently, spatial flexibility allowed by the use of robots and flexible optical fibres, coverage of a larger amount of total surface that can be achieved during welding process and reduction of the mobile mechanical basis in the geometry system, caused by the low weight of the optical heads. The relative robustness and compactness of the Nd: YAG laser and the possibility for a narrow beam it produces to be transmitted to the work piece via silica optical fibres are two main features.Thus,easy manipulation and control of Nd: YAG lasers through optical fibre delivery provide welding opportunities for complex geometries where 3D welding can be carried out. In terms of weldability for metallic materials, Nd: YAG laser has various advantages compared to CO_2 laser, so the application of Nd: YAG laser to weld metallic materials is steadily being increased(S. Nishimura).

Selection Of Viable Nature Of The Laser Beam For The Welding Process

Generally, different lasing mediums can transmit the laser beam in three possible modes as follows,

1. Continuous mode, 2. Pulsed mode and 3. Q-switched mode

The so-called Q of a laser cavity is the ratio of stored energy to cavity loss per round trip. In Q switching, energy is stored in the laser rod by optical pumping. The laser is prevented from oscillating by introducing a controllable loss. Q switching mode is most widely used for marking applications.

In a continuous wave (CW) laser, the output power of the laser is constant with time. During CW laser beam welding, the beam forms a stable molten weld pool as long as the beam is on. The heat input to the material during the processing is then eventually distributed by the processing speed (welding velocity). However, there are two main problems in continuous wave laser beam welding: lack of penetration and the inverse “dropout”. These are the boundaries for a good weld made with a given power of CW laser. The maximum welding speed for a given thickness rises with an increase in power. Since, mean power is constant for CW laser hence the welding velocity limited and causes slight penetration depth during welding of thick materialsmodes (J. F. Ready).

Advantage Of Pulsed Laser Over Continuous Laser

The use of pulsed laser shown advantages than CW laser that arevery low distortion and the ability to welding heat-sensitive and high reflective materials. During the pulsed laser welding process, the work piece is heated up to the melting point consecutively by short duration pulses, producing a series of overlapping laser spots (Jamshid Sabbaghzadeh). The short pulse length and high peak power at relatively low average energy gives low heat input sufficient to the welding leads to the low distortion than CW laser. Thus, control of the total amount of energy delivered to the material during processing is a very important in the consideration of deciding nature of laser(William M. Steen).

The use of pulsed power introduces two more variables to be considered: pulse repetition rate and percentage overlap. The welding velocity can be

The welding speed = Spot size × Pulse Repetition Rate× (1−Overlap fraction).

Hence,speed is independent of power. Penetration is a function of power and there can be greater penetration for a given average power that may useful to weld thick materials. The increased peak power is useful for welding of reflective material, since the keyhole is initiated more quickly. Higher peak power also means greater tolerance to focal position and pulsing means less energy is deposited in the workpiece, leading to reduced distortion (T Kugler).

These advantages for pulsing have been noted with the further advantage that pulsing allows better control over the flow in the weld pool and can under the correct conditions reduce the formation of pore, less spatter and smoother bead shapes (Holtz). Pulsing was able at the correct speed and pulse rate to allow porosity-free lap welding of zinc-coated steel (Katayama S). It was also able to reduce the porosity in thick-section welding with a 20 kW laser beam by pulsing at the oscillation frequency of the weld pool, leading to the resonance effect (Tsukamoto S). For welding, the pulse is usually longer than for drilling and cutting. Selection of nature of lasing mode ascontinuous/pulsed beam and their prominent parameters for materials compatibility of different material processing are discussed (K. SureshKumar).

Minimum Heat Input: Pulsed Nd: YAG laser is the choice. If components have metallurgical constraints on heat input or there are heat-sensitive components nearby such as glass-to-metal seals or O-rings, the pulsed YAG can be set up to achieve the required processing rate at a heat input low enough not to damage the components.

Speed: CW Nd: YAG laser is the best choice. Whether cutting or welding, by processing the component with a CW beam there is no need to overlap pulses or to re-establish the keyhole. Simply adjust power and speed along with the focus spot size to achieve the desired penetration.

Welding Reflective Materials: Usually pulsed Nd: YAG lasers. For copper and precious metals the pulsed Nd: YAG laser has the peak power to break down the reflectivity. Only very high average power CW Nd: YAG lasers can process these materials.

Heat Treating/Cladding: Usually CW Nd: YAGlasers. Average power tends to be the limit to speed, case depth, or remelt thickness. Pulsed Nd: YAG lasers can do the job but their lower average power ratings rule them out except for small devices.

Spot Welding: Usually pulsed Nd: YAG lasers. By setting the pulse parameters correctly, the pulsed laser is the fastest and most repeatable spot welder. Only if large diameter pieces are required would a CW laser be considered.

Low Penetration Welding: CW laser will weld very quickly and produce parts with high throughput. Pulsed lasers might have sufficient speed also and have the benefit of dealing with material changes or spot welding requirements.

Welding Crack-Sensitive Alloys: CW Nd: YAG laser is the best choice unless there are other constraints such as heat input. The slower cooling rate of the CW laser usually reduces cracking tendencies. This is true of steel alloys containing sulphur, phosphorus, lead, and/or selenium. Also for welding mild steel to stainless steel or steels with poor Cr: Ni equivalent ratios(O.A.Idowu).

Influence Of Operating Parameter Of The Laser Welding Process

The quality of a weld joint is directly influenced by the welding input parameters, therefore, welding can be considered as a multi input, multi output process. The figure 5demonstrating the process parameters those affects the quality of pulsed laser welding. But, a common problem that has faced the manufactures is the control of the process input parameters to obtain a good welded joint with minimal detrimental. In order to overcome this issue, optimization techniques can be preferred to obtain set of most influential input variables for welding through mathematical models. The characteristic variables involving in the process of welding have been classified in to three main categories as presented in table 4.

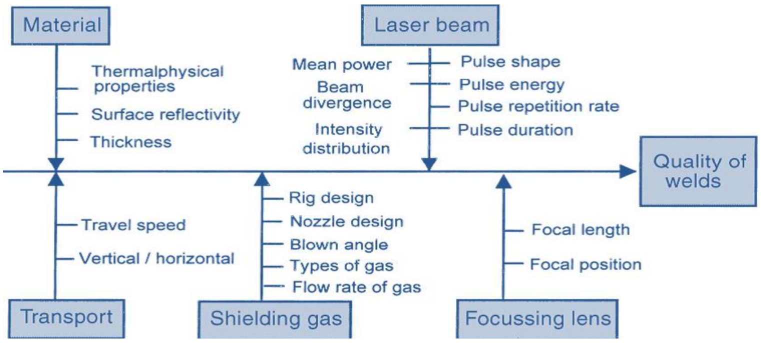


Figure 5: Demonstrating the process parameters affecting the quality of pulsed laser welding (Y. –F. Tzeng).

Table 4: Many possible input parameters and its influences on laser welding process.

Operating Factor		Phenomenological Factors	Product Factors
Absolute Factors	**Relative Factors**		
Power Source: **Wavelength, Power, Power Distribution (Pulse/Continuous), Spot Size, Focal Point, Pulse Shape, Divergence, Pulse Duration, Focal Position, Pulse Frequency Operating Mode.** Material**:** **Chemical Composition, Thermo - Physical Property, Microstructuregeometry.** Shielding Gas: **Nature, Chemical Composition, Flow Rate, Position And Angle.** Filler Material**:** **Chemical Composition, Thermo - Physical Property, Microstructure Geometry.** Position And Movement: **Position Of The Beam, Weld Direction, Gap Between The Weld Joints.**	Relative Position Of The Beam, Material, Filler Material, Shielding Gas. Relative Angle And Distance Between The Weld Materials. Welding Speed: Movement Between The Beam And Material. Movement Between The Filler Material And Beam (Feed Rate Of The Added Material).	Molten Pool Size, Solidification Speed, Chemical Composition, Surface Tension, Fluid Flow Dynamics, Shielding Gas, Pool Shape, Cooling Rate And Temperature Distribution	**Weld Bead** : Geometry, Penetration Depth, Bead Shape, Bead Height, Bead Width, Width To Penetration Ratio, Haz And Percentage Of Dilution. **Mechanical And Metallurgical Properties:** Hardness, Yield Strength, Residual Stress, Joint Strength, Impact Strength, Elastic Limit, Tensile - Shear Strength, Fatigue Life, Creep Strength, Thermal Distortion And Distortion

In CO_2 laser welding, the effect of magnetic field strength, laser power, welding speed, field direction and shielding gas (He (or) Ar) on the penetration depth and width of bead. The plasmas effect was achieved at low magnetic field strength and the penetration depth can be increased significantly under Ar atmosphere(H.C.Tsc). Effect of identified major process parameters such as laser power, average peak power density, pulse energy and traversing speed of the pulsed Nd:YAG laser seam welded steel sheet was analysed (Y.-F. Tzeng). The effects of laser power, energy intensity, welding speed, pulse duration and frequency are evaluated practically for INCONEL plate using a pulsed Nd: YAG laser beam (W J Han). Electro chemical tests of pulsed Nd: YAG laser welded Zinc coated steel sheet was carried out to verify the effects of a range of pulsed Nd: YAG laser welding parameters on corrosion are investigated, the variation in the pulses do not make any significant difference on electro chemical test (Y. –F. Tzeng).

Optimization of welding, cutting, perforation parameters of high-productive materials (such as Tungsten, Ti, Tantalum, Nb, Al and ceramics used in aerospace, nuclear industry, strip building etc.) with formation of laser cavities for multifunctional purpose is based on specifying output parameters like pulse energy, average power, pulse repetition rate, divergence, pulse duration, focal spot size and shape (S.V. Usov). Parameters of Nd: YAGlaser was optimized for welded Mg alloy via Taguchi analysis with the six welding parameters such as shielding gas, laser energy, conveying speed, welding focus position, laser pulse frequency and pulse shape (Lung Kwang Pan)**.**The welding parameters such as welding speed, inter-beam distance; power of laser, spot size was studied for galvanized steel welded by CO_2 and Nd: YAG laser (M.G. Forrest). Hot cracking is a phenomenon that frequently occurs in the laser welding of some "special" alloys such as Al-Mg-Si alloys, which can be avoided by the optimized parameters of welding speed and added material rate parameters (E Cicala). Laser power and interaction time was significantly affecting the clad shape of laser cladding by wire, lack of operator skills also affecting the cladding shape (Edoardo Capello).

The optimization capabilities in design expert software was used to optimize the keyhole parameters (maximize penetration depth, minimize the heat input, width of weld Zone and width of HAZ) in CW CO_2 laser butt welding of medium carbon steel by means of laser power, welding speed and focused positionUsing response surface methodology (RSM) (A. a. K Y Benyounis). Effect of thickness, laser power and welding speed on shape of weld area and hardness of the base metal of Ti6Al4V alloy was discussed by artificial neural networks and Taguchi approach (G Casalino). In laser welded ultra-fine grained steel (UFGS) minimum of HAZ size was carried out using cooling conductor liquid nitrogen. It was found that a shielding gas, with adequate flow rate for the liquid nitrogen depth was used to remove nitrogen from the area of beam irradiation to stabilize the weld bead (Hideki Hamatani).

Laser welding of seating small titanium tube ends (Hyoung Keon Lee) exposed that the pulse width and focal position had the greatest effects on the S/N ratio of the melted length. Optimized laser welding parameters via Standard orthogonal arrays of 18 different groups following Taguchi's suggestionfor titanium tube ends are given in figure 6and results for the melted length are given in table 5.

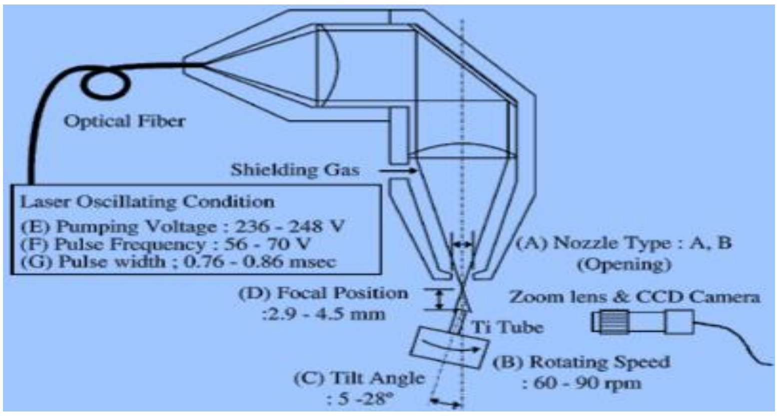


Figure 6: Optical arrangement of the Nd: YAG laser welding system and optimized welding parameters for welding of titanium tube (Hyoung Keon Lee).

Table 5: Laser welding parameter to an 18 orthogonal array and measurement of the melted length(Hyoung Keon Lee).

No.	Welding parameters							Average power (W)	Welding time (s) (250 J/W)	Melted length (mm)			
	A	B	C	D	E	F	G			Data		Average	S/N ratio
										1 (+0.15 mm)	2 (−0.15 mm)		
1	A	60	5	2.9	236	56	0.76	59	4.2	0.98	1.24	1.11	15.7
2	A	60	15	3.7	242	62	0.8	87	2.9	1.04	1.22	1.13	19.1
3	A	60	28	4.5	248	70	0.86	128	1.9	1.23	1.38	1.31	21.7
4	A	75	5	3.7	242	70	0.86	112	2.2	1.93	1.87	1.90	32.9
5	A	75	15	4.5	248	56	0.76	84	3.0	0.67	0.93	0.80	12.6
6	A	75	28	2.9	236	62	0.8	73	3.4	0.73	1.12	0.92	10.3
7	A	90	5	2.9	248	62	0.86	114	2.2	2.33	2.91	2.62	16.0
8	A	90	15	3.7	236	70	0.76	76	3.3	0.73	1.13	0.93	10.2
9	A	90	28	4.5	242	56	0.8	79	3.2	0.91	1.44	1.17	9.7
10	B	60	5	4.5	242	62	0.76	80	3.1	0.06	0.18	0.12	1.4
11	B	60	15	2.9	248	70	0.8	114	2.2	1.27	1.49	1.38	18.9
12	B	60	28	3.7	236	56	0.86	76	3.3	0.90	1.15	1.02	15.3
13	B	75	5	4.5	236	70	0.8	84	3.0	0.06	0.16	0.11	2.2
14	B	75	15	2.9	242	56	0.86	89	2.8	1.25	1.29	1.27	33.0
15	B	75	28	3.7	248	62	0.76	93	2.7	1.21	0.86	1.03	12.4
16	B	90	5	3.7	248	56	0.8	92	2.7	0.99	1.31	1.15	14.0
17	B	90	15	4.5	236	62	0.86	84	3.0	0.35	0.57	0.46	9.1
18	B	90	28	2.9	242	70	0.76	90	2.8	0.98	2.24	1.61	4.4

The welding current and pulse width had great influence on the quality of the laser welded Ni Ti Alloys joints by changing the microstructure and mechanical property at the joint position (Y G Song). It was observed from the laser steel sheets that as the laser energy increases, the penetration depth, bead length and bead width of the welded spot increases. Similarly, the laser incident angle increases, the penetration depth, and the bead width increase while the bead length decreases (Yi ChunLiao). Using design-expert software, design matrix was established to analyse the relationships between laser parameters (Laser power, welding speed, and focal point position) and three responses (Tensile strength, impact strength and joint operating cost) and compared with experimental results (K.Y.Benyounis). The laser welded dissimilar joint of AISI 316 stainless steel and AISI 1009 low carbon steel plates, fusion zone area and shape as a function of the laser parameters power, welding speed, and defocusing distance are evaluated using Taguchi approach with Design of experiment technique (E.M.Anawa). The effect of temperature and clamping force during Nd: YAG laser butt welding. The thermal expansion, cooling contraction and work piece width reduction during welding induce variation in the pre-set clamping force and consequently changing the weld joint strength are discussed(Quan Sheng Liu).

An attempt made to optimize the operating parameters involved in an autogenous pulsed Nd: YAG laser welding process of similar and dissimilar combinations of butt joint of 2 mm thick 316 L stainless steel and mild steel(A. J. K SureshKumar). In laser welded copper-stainless steel dissimilar connections, influence of the feed state and the lateral beam displacement on the joint quality results no formation of cracks, improved mechanical strength and the electrical conductivity (M.Weigl). The performance of the pulse is limited by the laser pulse peak power, spot size and pulse repetition rate. Therefore, large pulse overlaps and continuous heating is often more suitable for sintering purpose (Tero Kumpulainen). The welding speed, energy input and heat source distributions have important effects on the shape, boundary and peak temperatures of fusion zone and HAZ in butt joint weld (D.Gery). In laser welding of AISI 904L stainless steel, the interaction effect of beam power and travel speed have more influence than other factors followed by beam power, travel speed and focal position to Argon and nitrogen shielding gases (P Sathya).

Induction preheating at 800°C laser welding was performed with filler metal additions to weld 1N 738 in orders to reduce the weld defects such as cracks, under fill and porosity in the weld (M.FChiang). The transmission welding experimentation studies the relationship between average power travel speed and weld peel strength of carbon nano composite materials using direct diode and Nd: YAG laser welding (A.P. Wu). The weld penetration was deeper when higher laser power focus height, smaller torch angle in hybrid welding of Al-Mg alloy using MIG-CO_2 laser (G.Casalino). Correlation between cracking behaviour, hardness of the beads and misalignment due to laser power, welding speed, shielding gas and shielding gas was investigated for autogenous welding of hastelloy X to Maas-M247 (Zhang Li). The possibility of controlling and précised application of material processing usingprominent operating parameters such as average peak power, average peak power density, mean power, pulse duration, pulse energy, pulse repetition rate are discussed (SureshKumar and A Jayanthi).

Influence Of Optical Fibre In Laser Beam Delivry

An ideal delivery system should have an efficiency as near to 100% as possible, not to be subject to damage by the laser power, to be flexible, to have a low out divergence and should be applicable over as broad a wavelength spectrum as possible. Nd: YAG lasers with increased output powers and improved beam qualities are preferable for the transmission of high power laser beam through fibre optic delivery systems. G. Nath has performed hand held laser welding for the first time using fibre optical delivery system. It can transmit pulses laser in excess of 25 J with an efficiency of 85%. During several hours of observation no attenuation of transmitted beam was found (G.Nath). The demonstration of beam quality as a function of power of different laser sources, covered for several laser materials processing as shown in figure 7.

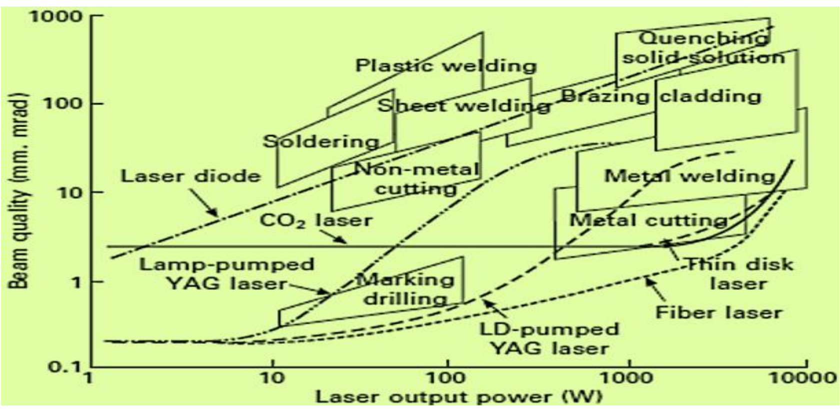
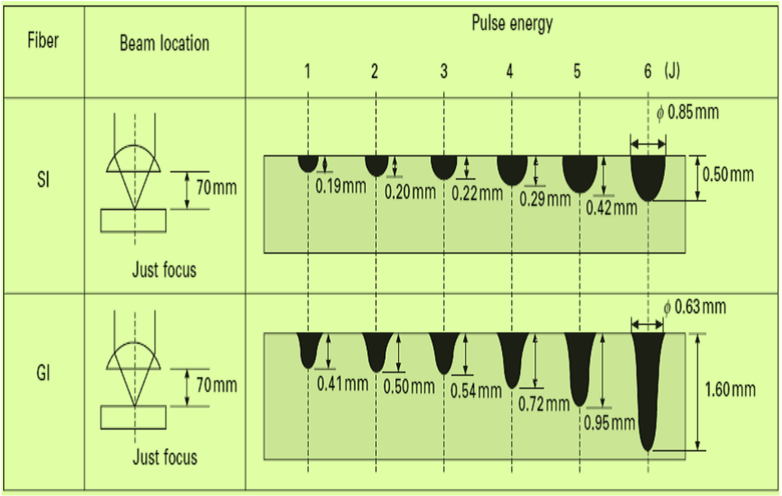


Figure 7: Beam quality as a function of laser power for different laser sources for several laser materials processing (NasirAhmed).

The laser has been effectively transmitted through a core dia of 400 µm and 0.2 NA silica-silica optical fibres with transmission efficiency of more than 90% in the whole range of operation. This laser system has been effectively utilized for cutting of stainless steel sheets of up to 14 mm and keyhole welding of carbon steel up to 2 mm penetration depth (B.N. Upadhya). For welding, the association of step-index fibre/pseudo-pulsed mode and Graded index-continuous mode has to be chosen (F.Lemoine). The comparison of the effect of graded index and step index fiber on spot weld penetration are given in table 6.

Table 6: The effect of penetration depth of spot welding using step index and graded index fiber(Shiner).



The nature of the fibre is step or graded index, only minor differences are existed. But from industrial point of view, the step index fibre is feasible for easy implementation (Andrei Boglea). Laser beam transmitted through a fibre about 225 m distance to a remote welding tool inside a steam generator tube(Jae-Do Kim), it's greater distance than previously reported distance 70 m (Panora Psyllaki) and 150 m (A.Zombon). It has been exploited commercially for various material processing applications in harsh environments. Over the last two decades, lamp pumped Nd: YAG laser with fibre optic beam delivery has proved to be most rugged and widely used system in industrial environment.

Effect Of Shielding Gas In Laser Welding

The selection of the shielding gas should take into account chemical and metallurgical process between the gases and molten pool. The shielding gas affects all the welding characteristics such as shape, penetration, efficiency etc…The nozzle design assures the protection against material oxidation using minimal gas flow rates an increasing the welding penetration in the case of high power Nd: YAG laser welding (D.Gery) and (J. F. Ready). The denser gases like nitrogen or argon improves the welding penetration by mechanical pressure and low density of helium leads to a pressure profile relatively stable due to no critical distance for common flow rates.

During under water Nd: YAG laser welding of AISI 304 stainless steel, the welding quality is severely influenced by the shielding condition of the local dry cavity. The effect of shielding conditions, water flow rate, gas flow rate and water flow angle, on the stability of the local dry cavity study shows the relationship between the shielding condition and the quality of weld bead (Xudong Zhang). Properties of gases and gas consumption rate during laser welding being used in industry are given in table 7 and table 8.

Table7: Gas consumption in laser welding used in industry(J. F. Ready).

GAS TYPE	COAXIAL NOZZLE		OFF-AXIS JET^{A}	
	CO_2	ND:YAG	CO_2	ND:YAG
Helium or mixtures with high helium content	10-30 litre/min	10-30 litre/min	10-40 litre/min	10-30 litre/min
Argon or mixtures with high argon content	Not suitable	05-20 litre/min^{b}	20-40 litre/min	5-20 litre/min^{b}
a Recommended for welding with more than 8 kW laser power b Flow rate reduced due to specific weight of argon				

Table 8: Properties of gases used in laser welding (J. F. Ready)

Gas	Density	Ionization Potential	Thermal Conductivity
	Kg/M^3	Ev	10^{-4} W/M. K
Argon	1.650	15.7	161
Carbon Dioxide[b]	1.1833	14.4	157
Helium	0.165	24.5	1482
Hydrogen[b]	0.0834	-	174
Nitrogen[b]	1.153	15.5	250
Oxygen [B]	1.326	13.2	2.39

[A] The Values For The Density Are Valid At 70º F (21.1ºc) And 1 Atm.
[B] Dissociation Energy Has To Be Considered In Polyatomic Gases.

Nitrogen, argon and helium pure gases are taken in to consideration of different nozzle inclinations and flow rates in order to obtain the sound beads and reliable manufacturing (G.Tani). Welding configuration (a) with a shroud gas feed tube and in a gas box (b) was shown in figure 8(Jinhong Zhu). Gases with similar densities behaves in the same way with respect to shielding power lower density, poor weld protection, high density better weld protection, however, flow rate not affecting the protection in case of high density. The distance from the beam - material interaction zone plays vital role in shielding gas contamination prediction.

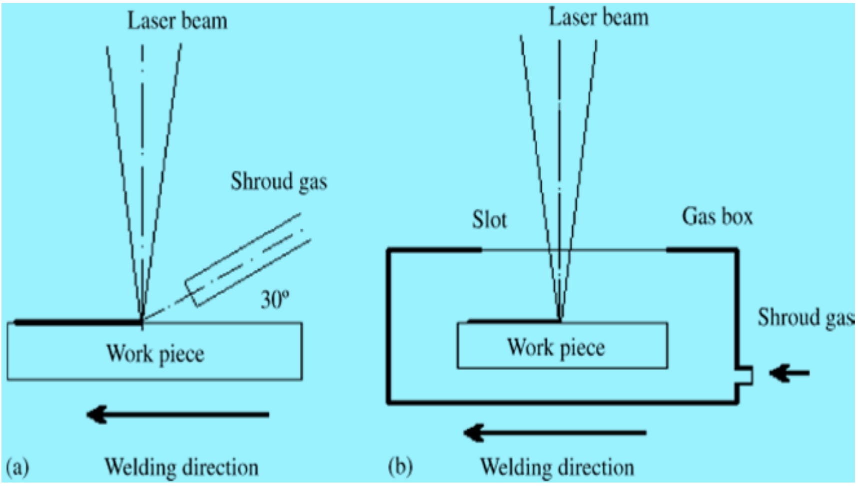


Figure.8. Welding configuration (a) with a shroud gas feed tube and (b) in a gas box.

An experiment of CO_2 laser-TIG hybrid welding with different shielding gas methods was carried out on the 316L stainless steel plate, demonstrate that full weld penetration denoting efficient synergetic effect only cab be obtained under appropriate shielding gas parameters (Ming gao). In Laser-MIG hybrid welding of AISI 304 stainless steel plates in a zero gap butt joints configuration, the effects of gas flow rate and gas composition was studied. A shielding gas flow between 10 and 30 l/min is enough to grant a suitable cost effective welding environment (Masao Toyoda). In laser welding of Ti-6Al-4V, the characteristic size of argon gas shield is larger than that of helium gas shield, that smaller nozzle inclination angle, gives larger characteristic shield size that the flow rate increased the protection zone will be increased (Hong Wang). The surface of AISI 304 stainless steel was melted in Argon and nitrogen atmosphere using different laser beam scan rates and gas flows, the results shows that in both cases the laser surface melting (LSM) induced improvement in pitting resistance with respect to the base steel (A. Conde).

Different concentrations of oxygen in the surrounding environment was studied owing to its significant influence in heat and mass transfer, liquid metal flow during stationary laser welding (spot welding) charge in the surface tension temperature gradient and absorption coefficient observed for different concentrations of oxygen (C.X.Zhao).

Optimization Techniques For Laser Welding Parameters

A simple and easily understandable model was developed by (Emin Bayraktar) to predict the relative importance of different factors (composition of the material and welding process conditions) in order to obtain an efficient welding joints from LASER, TIG and RSW welding techniques. This model is based on thermal, metallurgical and mechanical and also in situ test conditions. The construction of welding limit diagrams (WLD) that allows us to predict the values of the parameter in order to obtain an efficient welding joint. This approach is an efficiently way to separate the responsibility of the steel makes and welding designer for increasing reliability of joint structure.

In 2008, (Benyounis and Olabi)have reviewed many process of optimization of different welding process using statistical and numerical approaches until 2007. This provides some insight gained in the use of Design of experiment (DOE), Artificial neural network (ANNS), Response surface methodology (RSM), Taguchi window analysis, Factorial design, Genetic Algorithm (GA), Linear regression and other technique like controlled random search (CRS), Genetic algorithm welding strength estimation model (GAWSEM) for optimizing weld bead geometry and mechanical properties (Refer table 9). Combination of two optimization techniques, such as GA and RSM would real good results for finding out the optimal welding conditions.

Table 9: Common modelling and optimization techniques with their features of laser welding (Benyounis and Olabi).

S.No	Modelling Methods / Purposes	Features (Depends On Welding Methods & Parameters)
1.	**Factorial Design**: Hardness, Notched Tensile Strength, Joint Strength, Fatigue Life, Tensile Shear Strength, Elastic Limit And Ultimate Tensile Strength.	Weld Bead Geometry And Shape Relations Such As Penetration, Width, Reinforcement Height, Width To Penetration Ratio And Percentage Of Dilution.
2.	**Linear Regression**:Yield Strength, Notched Tensile Strength, Torsion Stiffness, Elastic Limit And Ultimate Tensile Strength.	Melting Rates, Total Fusion Area, Bead Height And Bead Width.
3.	**Response Surface Methodology**: Impact Strength, The Axial Pressure, Initial Rubbing Velocity, Moment Of Inertia And Breaking Strength, Ultimate Tensile Strength And Distortion.	Cladding Geometry Depth Of Penetration, Width, Height Of Reinforcement, Weld Width And Percentage Of Dilution.
4.	**Artificial Neural Network:** Hardness, Yield Strength, Residual Stress, Joint Strength, Impact Strength, Tensile - Shear Strength, Thermal Distortion And Distortion.	Neural Network Of Weld Modelling Corresponding To Bead Width, Penetration Reinforcement Height And Bead Cross Sectional Area.
5.	**Taguchi Method:** Impact Strength, Notched Tensile Strength And Ultimate Tensile Strength.	Weld Pool Geometry Front, Back Height And Width.

Importance Of Laser Welding On Stainless Steels

The various types of stainless steel are identified and guidance given on welding processes and techniques that can be employed in fabricating stainless steel components without impairing the corrosion, oxidation and mechanical properties of the material. Hence, the largest market for laser welding is the automotive industry where it is being applied to the welding of range of 0.7 mm to 3 mm coated and uncoated steels, transmission components and the fabrication of sub-assemblies.

The four grades of stainless steel have been classified according to their material properties and welding requirements:

- Austenitic
- Ferritic
- Martensitic
- Austenitic–ferritic (duplex and super-duplex).

Austenitic stainless steels (300 series) are used in applications requiring corrosion resistance and toughness. These steels find wide ranging applications in the oil and gas, transport, chemical, and power generation industries and are particularly useful in high temperature environments. There are a number of potential benefits that result from using high power Nd: YAG laser welding of stainless steels, including productivity increases. The low heat input of the laser welding process reduces the width of the HAZ, thus reducing the region that may be susceptible to pitting corrosion.

Ferritic stainless steels (400 series steels) do not possess the good all-round weldability of the austenitic grades. Laser welding of the ferritic grades in some cases impairs joint toughness and corrosion resistance. The reduction in toughness is due in part to the formation of coarse grains in the HAZ and to martensitic formation which occurs in the higher carbon grades. The heat-affected zone may have a higher hardness due to the fast cooling rate.

Widely GTAW process is used extensively for welded fabrication in power plants, but, laser assisted GTAW is being utilized for welding of higher thick sections and the most significant application is laser welding of thin/lower thickness tailored blanks.Austenitic stainless steels can be laser welded, with the exception of free machining grades which are susceptible to solidification cracking due to high sulphur content. Ferritic stainless steels with relatively low carbon and chromium contents are also readily laser weldable, an autogenous butt joint welding of 2 mm thick low carbon ferritic steel achieved using a pulsed Nd: YAG laserbeam(K.SureshKumar). The advantages of laser welding of stainless steel over other welding methods are listed in table 10(R.A.Willgoss). Only, few works have been reported on the austenitic and ferritic dissimilar welding using laser welding.

Table 10: A sample of advantages of laser welds over other methods (6mm thick 316 SS).

WELDING PROCESS	LASER	e BEAM	TIG	PLASMA
Total power used	50 kW	6 kW	3 kW	**6 kW**
Power absorbed by workpiece	4 kW	5 kW	2 kW	**4 kW**
Traverse speed	16 mm s $^{-1}$	40 mm s $^{-1}$	1 2 mm s $^{-1}$	**6.7 mm s $^{-1}$**
Alignment accuracy required	± 0.5mm	± 0.3 mm	± 1.0mm	**± 1.0mm**
Energy input	250 J mm $^{-1}$	125 J mm $^{-1}$	1000 J mm $^{-1}$	**600 J mm $^{-1}$**
Possibility of all positional welding	YES, but requires Optics to manipulate the beam. Optimum when moving work piece	YES, but requires mechanics to move gun. Optimum when moving work piece	Serious penetration characteristic changes with attitude	**Serious penetration characteristic changes with attitude**
Distortion (Axial shrinkage)	Minimal (small HAZ)	Minimal (small HAZ)	Significant ~ 1 mm on 5 mm plate	**Significant ~ 1 mm on 5 mm plate**
Distortion (Angular)	Minimal parallel sidedness	Minimal parallel sidedness	Significant V shaped weld	**Significant V shaped weld**
Surface profile defects	Very fine flow lines	Produces ruffled scarf on blackface	Underside protrusion held in by surface tension	**Underside protrusion held in by surface tension**
Special requirements for process operation	Safety interlock to guard against misplaced beam reflections	Vacuum chamber Local vacuum X-ray screening	Normal light Screening	**Normal light screening**
Process end at Start	Slight surface protrusion	Slight surface protrusion	Smooth	**Slight surface protrusion**
Process end finish	**Smooth**	**Slight surface protrusion**	**Smooth**	**Slight surface protrusion**

Laser Beam Welding On Stainless Steels

It has been reported that many applications using stainless steels made components with thickness in the range of 2 to 10 mm (G.Nath), which can be weld autogenously using laser or laser assisted hybrid welding. For instance, stainless steel and titanium sheets and tubes are seam welded using CO_2 laser (C.Ruffler), AISI 409 stainless steels welded by GMAW (or) GTAW at welding speed of ≤ 2.5 cm/s, but, laser beam welding with its rapid speed and relatively low thermal distortion has resulted in the erosion of gas GMAW and GTAW (R Akther). The fabrication of the hydraulic valves of AISI 304L to AISI 12L13 stainless steels butt welded, to control solidification cracking and micro fissuring (E V Van Osch).The microstructural characterization of both weld beads and heat affected zones (HAZ) on austenitic stainless steel (AISI 304 SS, AISI316 SS) and duplex stainless steel (UNS 31803)(A.Zombon) was studied.

Conventional welding processes produce cracking in irradiated stainless steel containing 1 to 12 appm helium from (n,α) reactions (W.R.Kanne),but, laser welding reduces tritium concentration enhancement in the heat affected zone of AISI 316 steel and consequently a possible embrittlement of the material (A.Roustila).Unirradiated AISI 316L stainless steel plate was lap jointed to the irradiated AISI 304L stainless steel plate under various heat inputs.Tensile tests results reveal that fractures not occurred in irradiated materials but in the unirradiated materials and shows good mechanical properties (S. Nishimura).Tailored blanks of stainless high alloy and non-stainless ferrite steel laser welded by melting with a filler material to achieve satisfactory mechanical properties (J. Tusek).

It has been shown that high dilution single sided welding of AISI 316LN stainless steel is a feasible option either as a submerged or as a laser weld. In each case the properties are acceptable and corrosion requirement have been met. But the situation regarding autogenously laser welding had till to be fully resolved (N.A. McPherson). AISI 430 Stainless Steel and a ferritic material lap joint made using diode laser(F.Curcio). Nd: YAG laser welding of AISI 304 stainless over RSEW joint has advantages of reduced porosity, improved energy efficiency and nohot cracking/thermal distortion. High peak power/short pulse lasers are well suited for precise welding of stainless steels under optimal conditions (Danny P'ng). Effect on bead profile and micro structural characterization of a CO_2 laser welded AISI 304L super austenitic stainless steel joints was employed by various input parameters (such as beam power, travel speed, focal position) and two different shielding gases (Argon and helium) (P Sathya).

The loss of metal due to the existence of vapour plume at the bottom of the keyhole that causes undercut during Nd:YAG laser welding of butt joint of AISI 316L stainless steel sheetautogenously, which can be eliminated by back forging or by optimizing input parameters (K.SureshKumar).

The temperature distribution, isothermal surface profile and deformation profile of the dissimilar joints of 316L stainless steel-low carbon ferritic steel joints for two different laser spot positions were simulated in order to find offset beam position for symmetrical weld pool across the butt joint(A. J. K Suresh Kumar).The heat and mass transfer across similar and dissimilar joints of 316 L stainless steel and mild steel made using pulsed Nd: YAG laser welding were investigated with the keyhole models simulated in terms of Peclet number(A. J. K Suresh Kumar).

The 1000Mpa grad complex phase steel is welded by CO_2 laser with a sufficient weld quality, joint has the strength as high as base metal, weld seam is in good correspondence with its martensitic microstructure, and its tensile strength reaches 1300Mpa (Jian Huang).Laser rewelding of irradiated 316 L (N) of the water cooling pipe lines repairs, the effect of helium generation on the mechanical properties of the weld joint was studied for unirradiated/irradiated 316 L (N), IG sample.A pair of 2mm thick AISI 316L stainless steel sheets that are successfully butt welded autogenously using irradiating pulsed Nd: YAG laser(K.SureshKumar).Some of the new applications that involve the use of stainless steel are also discussed up to date till 2009(K.H. Lo).

Laser Beam Welding On Materials Other Than Stainless Steels

Due to higher energy absorption of laser beam even by high reflecting materials such as copper, Aluminium and their alloys are steadily being increasing in industrial and domestic utilities. For instance, high temperature structural applications intermetallic compounds of Ti-Al (K.Uenishi), waspaloy (4mm) sheets (Zhang Li), Inconel 718 sheets (S Gobbi), Titanium sheets (Qi Yunlian), SiC particle reinforced Aluminum matrix composites (H M Wang), Light weight components built with Aluminum, titanium, magnesium and their alloys (E Schubert), Magnesium alloys (Sorin Ignat), (Jinhong Zhu),(Gang Song), (A H Wang) and (Nicolas Pierron), Aluminum alloys (Braun), (T Y Kuo), (A Haboudou), (Aniruddha Kumar) and (D. Triantafyllidis),Titanium alloys,Nical alloys, Copper alloys and Zirconium alloys(M.W Turner), (H Gugel) and(Jong Hyun Kim)have been laser welded and related mechanical and metallurgical properties have been investigated on in order to improve their efficiency in respective field of applications.Summary of compatibility of materials and laser sources being used for welding are given in table 11.

Table 11: Summary of the materials being welded using laser (J. F. Ready).

MATERIALS	COMMENTS
Aluminum alloys	5000, 6000 series up to 3 mm depth-both require filler material: Nd: YAG lasers offer benefits over CO_2lasers in terms of requiring filler material
Copper	High laser beam quality allows welding up to 3 mm sheet
Cast irons	Nodular cast iron can be welded with nickel filler wire
Nickel alloys (Hastelloy, Inconel, Waspaloy)	Some are highly weldable, subject to specific alloying elements
Steels – low carbon (> 0.2 %)	Highly weldable
Medium and high carbon (> 0.2 %)	Weldable, requiring filler and/or heat treatment
Alloy steels (BS4360 50D)	Structural and pipeline steels are weldable, levels of Mn, S, Si elements are important considerations
Stainless steel: Austenitic (AISI 304-321)	Highly weldable (exception of 303 and 303e)

Stainless steel: Ferritic (AISI 403-446)	Grades with low carbon and chromium weld best.
Stainless steel: Martensitic (AISI 410-440)	Problem with HAZ embrittlement-filler and post welding heat treatment are required
Titanium alloy (6Al-4V-Ti)	Highly weldable with all usual precautions and preparations are made
Plastics (thermoplastics-Polyethylene, Polypropylene)	Thin sheets weldable up to 300 µm. absorption tuning of sheets/laser and use of interface dies can enhance weldability. Penetration depth up to 3 mm has been attempted.

Since, an electron beam welding (EBW) has its own limitations; certainly, laser welding will be an important joining technique for various combinations of family of stainless steel and other materials with their increasing applications as discussed. Hence, it's necessary to update knowledge on laser welding process for considerations and implementations.

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