# INVESTIGATION OF Nd: YAG LASER WELDING EFFICIENCIES FOR INCONEL 625 PLATES

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**Abstract -** Laser beam welding (LBW) is a field of developing significance in industry concerning conventional welding systems because of lower measurement and shape twisting of parts and more prominent handling speed. Beat Nd:YAG laser welding attributes of Inconel 625 material (2.5 mm thick) were investigated. The microstructural and microhardness perception has been made by trial strategies and plans of tests were utilized to direct the experiments. The laser material collaboration, controlling of process parameters and their impacts on dissolving, cementing and prepare effectiveness are basic to comprehend the conduct of the weld joints. This paper expects to ponder the impact of welding rate on various process efficiencies in Inconel 625 material. A novel semi-observational strategy in view of weld pool volume measure from exploratory results is utilized to anticipate the softening proficiency of Nd: YAG laser welding process. The dimensionless parameter models are utilized to gauge different sorts of quantifiable controlling parameters. The result of the outcome demonstrates the critical impact of viable parameters on dissolving proficiency and vitality move productivity in welding of Inconel 625 plate. The perception of imperfections free welds has been related with welding efficiencies. The laser power and welding velocity are noteworthy process parameter that enhanced the efficiencies of welding. From the outcomes one can choose fitting welding pace and preparing conditions to get sought efficiencies.

***Key Words*: *LBW; Inconel 625; Weld pool Volume; Melting Efficiency; Process Efficiency***

## 1.INTRODUCTION

Inconel 625, a nickel based superalloy has been broadly utilized for different applications like aviation, warmth exchangers, compound industry, electrochemical industry and power era plants. A standout amongst the best welding methods for joining high-temperature materials is laser shaft welding. It is favored for its profound entrance, high speed, narrow heat affected zone (HAZ), well welding crease quality. It is extremely fundamental to comprehend the conduct of laser material collaboration, controlling of process parameters and their impact on liquefying, cementing and proficiency. Amid laser welding process, the laser bar vitality is kept up beneath the vaporization temperature of the work piece. The proficiency of the laser welding procedure depends on the measure of warmth used for softening the substrate material. The distinctive sorts of effectiveness in laser welding procedure are considered as a component of controllable process factors to be specific laser vitality exchange proficiency, dissolving productivity, coupling effectiveness and process proficiency. The laser power and welding velocity are critical process parameters however the measure of force consumed by the substrate materials relies on upon welding speed.

## 2. ESTIMATION OF PROCESS EFFICIENCIES

The attributes of a laser welding process relies on welding speed , laser control, beat length, bar edge, size of the weld pool geometry, warm properties, handle efficiencies and others. The effectiveness of the welding procedure can be enhanced by completely using the power provided to soften the substrate material.

### 2.1 Energy Transfer Efficiency

The vitality exchange productivity is a noteworthy element which is characterized as the proportion of warmth consumed by the work piece to the occurrence laser vitality. The estimation of vitality move effectiveness in CO2 laser welding process has been done tentatively by method for calorimetric procedure. In view of the writing study, the aggregate vitality consumed by the substrate (Ecal) is dictated by plotting yield voltage versus time flag. The region under the bend can be controlled by joining and after that it will be duplicated by the calorimeter adjustment steady (0.598W/V). The condition (1) proposed by Unocic(2004) is utilized to figure vitality exchange proficiency.

$$\eta_e = E_{cal} / P_o\, t \qquad (1)$$

The vitality retained in laser welding process rely on upon the weld pool pit and the net vitality exchange to the substrate. The energy exchange to the substrate material is the contrast between laser vitality retained and warm misfortune to the encompassing. The vitality consumed by the material relies on different inward impression of laser beams and weld pool shape. The shallow welds retains little portion of laser vitality and profound wells ingest more noteworthy vitality when the weld infiltration ways to deal with a more prominent profundities.

The relationship between vitality exchange productivity and weld entrance introduced in equation(2) proposed by Feurschbach and McCollum(1995) as far as laser beam assimilation, key hold measurements, and episode laser beam edge.

$$\eta_e = 0.9[1 - R^{\left(\frac{\Pi - \phi}{2\tan^{-1}\left(\frac{r_k}{d}\right)} - 0.5\right)}] \quad (2)$$

The liquefying proficiency of the welding procedure can be anticipated by utilizing material autonomous model recommended by Feurschbach(1996) given in equation(3).

$$C_y = \eta R_y[0.48 - 0.29\, exp(\eta R_y/0.68) - 0.17\, exp(\eta R_y/59)] \quad (3)$$

Where $C_h = Av^2/\alpha^2$ and $R_y = q_o v/\alpha^2 \delta h$

The obscure amounts in equation (3) can be registered utilizing Christensen and Gajendramundsen (1995) are utilized to gauge vitality exchange effectiveness and weld bead cross sectional territory. The weld bead cross sectional zone can be resolved from trial comes about get from the examples arranged for metallographic review.

### 2.2 Melting Efficiency

It is characterized as the measure of vitality that is utilized to make liquid pool from vitality convey to the work piece. A little bit of the vitality is utilized for dissolving the substrate material and rest of the vitality is dispersed to the encompassing range by various methods of warmth exchange. Softening proficiency is the proportion of dimensionless parameters Ch and Ry is proposed by Feurschbach (1999) exhibited in condition,

$$\eta_m = vA\delta h/\eta_e q_o \quad (4)$$

A semi-exact condition proposed by Unocic and DuPont (2004) is utilized to foresee the dissolving effectiveness are displayed in condition.

$$\eta_m = \frac{v\{\int_{T_O}^{T}(c_p(T)\Delta T) + \Delta H_f}{\eta_e t q_O} \quad (5)$$

The dissolving proficiency in bend welding process proposed by Okoda and DuPont (2002) can likewise be evaluated by method for power delivered to the substrate material which is given in condition

$$\eta_m = exp\left(-\left(1 + \frac{\Delta H_m \alpha^2}{1.14 P_i S}\right)\right) \quad (6)$$

The relationship amongst Ch and Ry got from the best fit curve is given in condition proposed by the A.P.Tadamalle et.al.

$$\eta_m = 0.65 + 0.016\left(\frac{\Delta H_m \alpha^2}{\alpha_e P_i S}\right) \quad (7)$$

The semi-exact condition is utilized for anticipating the liquefying productivity of Nd:YAG laser welding process. The preparing parameters, warm stream geometry and base metal thermo physical properties have noteworthy impact on liquefying productivity.

### 2.3 Coupling Efficiency

The coupling effectiveness is characterized as the proportion of vitality consumed by the weld to vitality yield from the laser source. The vitality consumed by the weld can be measured by calorimeter, thermocouples and measuring weld pool zones. The standardized speed (Ns) and standardized power (Np) are proposed by Nath et.al.(2002) is utilized to evaluate the coupling effectiveness is given in condition (8). It is characterized on the premise of force consumed by the metal for portraying the conduction welding process.

$$N_s = \frac{(vb)}{\alpha} \text{ and } N_p = \frac{P_{ab}}{t\, kT_m} \quad (8)$$

The power consumed by the material is processed by considering a wide range of misfortunes and vitality adjust condition. The relationship between dimensionless parameters in CO2 welding procedure is given in condition (9).

$$\eta_c = \frac{vwt\, T_m}{P_{ab}} \quad (9)$$

### 2.4 Process Efficiency

It depicts the aggregate sum of vitality used to make a liquid weld pool from the vitality conveyed to the work piece. The procedure productivity is characterized by Unocic et.al.(2004) as the result of vitality exchange proficiency and softening effectiveness as given in condition (10).

$$\eta_p = \eta_e \eta_m \quad (10)$$

The procedure proficiency relies on upon weld bead measurements, sorts of laser source, thermo physical properties and mechanical properties.

## 3. EXPERIMENTAL PROCEDURE

The Inconel 625 has been chosen for the examination of various efficiencies in Nd:YAG laser welding process. The thermo physical properties of the material and process parameters utilized amid experimentation are given as a part of Table 1 and Table 2 individually.

Table 1: Thermo physical properties of the Inconel 625 alloy

| Parameters | Values | Parameters | Values |
|---|---|---|---|
| Density | 8440 Kg/m$^3$ | Poisons ratio | 0.30 |
| Elastic modulus | 105 G Pa | Melting Point | 1623 K |
| Mean coefficient of Expansion | 16.2*10$^{-6}$ cm/cm$^0$c | Refractive index | 2.40Ni |
| Specific Heat | 427 J/Kg K | Diffusivity | 5.7 mm$^2$/s |

Table 2: Process parameter, Chemical and Mechanical properties of the material

| Parameters | Values | Parameters | Values |
|---|---|---|---|
| Gas flow rate | 7 lit/min | Pulse energy | 15.9J |
| Pulse duration | 2ms | Spotfocus diameter | 2mm |
| Frequency | 50Hz | Focal distance | 150mm |
| Beam angle | 90±5$^0$ | Proof stress | 275MPa |
| Yield strength | 534 MPa | Elongation | 45% |

The specimens are cut into 30mm * 30mm by utilizing wire slice electric release machine to stay away from twisting. The globule on plate is made on 2.5mm thick sheet by fluctuating welding speed from 550 mm/min to 1200 mm/min. The trial setup is appeared in Fig.1.

Figure 1. Experimental setup and Specimen arrangement

The weld tests were cut into transverse bearing and the cross sectional surface has been set up for metallographic investigation. The etchant, for example, glycergia is utilized to watch the small scale structure of the weld joint. The specimens arranged for metallographic investigations are as appeared. The weld dab geometry measurements are measured by utilizing a modified smaller scale scope. The physical perception of tests arranged for metallographic assessment uncovers that the profundity of infiltration declines with increment in welding speed. The full profundity of infiltration happens at a welding rate of 1200 mm/min.

## 4. RESULT AND DISCUSSIONS

The aggregate power consumed by the material increments with expanding weld speed. The impacts of welding speed on power consumed by the substrate material are appeared. A lot of warmth is used to make and keep up the liquid pool. This is because of vast sum power is retained to dissolve material past the welding velocity of 700 mm/min .The Nd:YAG laser pillar source is exceptionally intelligent to the metallic materials at a wavelength 1.064 .The reflectivity of the cleaned Inconel 625 surface is around 98% at room temperature and it lessens as the temperature of the surface ascents. The liquid pool of Inconel 625 material has reflectivity of 85% when laser beams are parallel to the profundity of entrance (8).

The heat loss to the surroundings is thought to be 10% of the assimilated the laser energy. The vitality exchange productivity got by considering calorimetrically measured estimations of laser yield is 92%.The material autonomous model and laser reflection strategy are utilized to figure vitality exchange effectiveness as for welding speed. The variety of 13% and 28% is seen from the material autonomous model and laser reflection technique respectively. The result got from these two model are displayed in Fig.4.Since the variety in vitality exchange effectiveness is huge , the liquefying proficiency is figured in light of models recommended by various scientists and the outcomes acquired are appeared in Fig.4

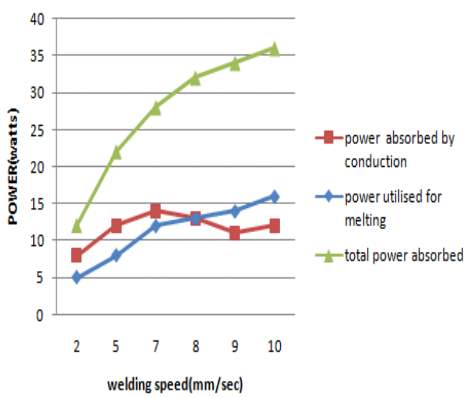

Figure. 2. Net heat absorbed by specimen at different welding speeds

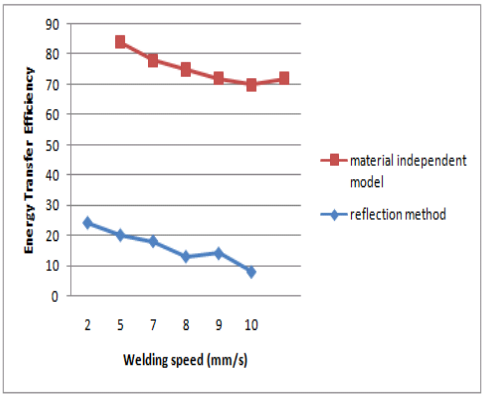


Figure.3.Variation of energy transfer efficiency verses welding speed

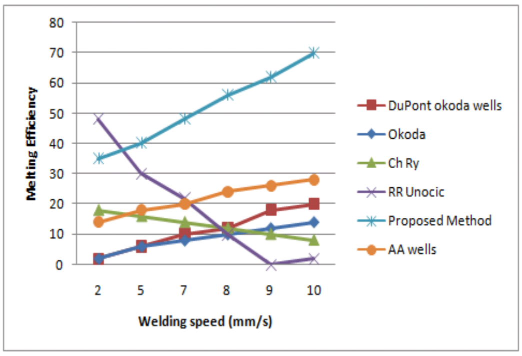


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Figure. 4. Melting efficiency verses welding speeds

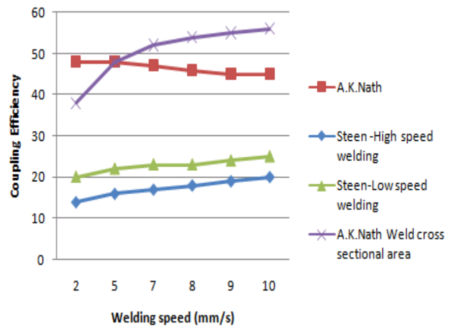


Figure.5.Variation of coupling efficiency verses welding speed.

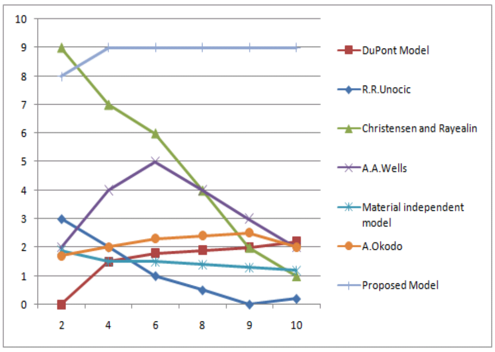


Figure.6. Effect of welding speed on process efficiency.

The assessed dissolving effectiveness by utilizing distinctive estimations of weld pool measurements acquired from altered magnifying instrument demonstrates higher esteem than every other model. The estimation in light of the warmth info is straightforwardly relative to the result of vitality provided, vitality exchange effectiveness and heartbeat recurrence. The dissolving effectiveness increments nonlinearly with diminishing welding speed. This is because of the choice of process parameters, for example, warm information, warm diffusivity, sheet thickness, weld globule geometry and enthalpy for the calculation of softening productivity.

The hypothetical greatest warmth exchange proficiency values for gas tungsten bend welding, circular segment welding and plasma curve welding procedures are 37 %, 44% and 48% separately. The most extreme and least benefit of softening proficiency acquired from semi exact technique utilizing Nd: YAG laser welding procedure is 37% and 68% individually .It is clear from the above perceptions that the dissolving productivity in light of weld pool volume increments with increment in welding speed.

The substrate material liquefying is more at higher velocities since less time is accessible for transporting heat far from the confined softened area. This is because of bigger measure of vitality is used to make and keep up liquid weld pool. In laser welding, the shaft coupling with substrate material is exceptionally subject to material properties in light of various estimation of optical reflectivity for various materials. The coupling productivity for high and low speed $CO_2$ laser welding is assessed. The Fig.5 uncovers that the welding speed assumes huge part in laser welding process, since coupling productivity increments with increment in welding speed. The coupling efficiencies in conduction and keyhole $CO_2$ laser welding procedure are 25% to 85 % separately.

The coupling productivity of Nd:YAG laser welding process got from the test results is 42% to 70%. The effectiveness evaluated by utilizing standardized speed and power parameters in Nd:YAG laser welding exists in the admissible range as acquired in $CO_2$ laser welding. The coupling proficiency can be expanded by quickening photon thickness level and welding speed, top power toward the start of the beat and enhancing the surface conditions identified with the absorptivity.

The procedure efficiencies are figured in light of material autonomous model and reflection technique. The greatest procedure effectiveness got from reflection technique and material autonomous model is 11.57% and 53.64% individually. The outcomes appeared in Fig.8 portrays that the procedure effectiveness increments with increment in welding speed. The reflection strategy portrays sensibly bring down proficiency than that of material autonomous model.It is because of different impressions of laser beams inside the material which is utilized for softening the substrate material. The material free model is produced by considering thermo mechanical and material properties, while reflection technique depends on number of inner reflections and profundity of keyhole.

The outcomes got from reflection strategy portrays that the shallow weld zone ingests little part of vitality and profound welds assimilates more prominent vitality when the weld entrance ways to deal with a profundity more than 1mm. It has been uncovered from the study that the procedure effectiveness increments with increments with increment in welding speed if there should arise an occurrence of semi exact strategy though in the event of reflection technique it is conversely relative.

## 5. CONCLUSIONS

The critical quantifiable parameter in welding procedure is process productivity. It relies on handling and working parameters, thermo mechanical and compound properties of the material, surface conditions and laser control source. The welding rate is altogether influencing on a wide range of efficiencies. It has been found that the measure of force required for liquefying the material is higher and warm diverted by conduction is lower at a welding rate of 7mm/s or more. The semi exact technique exhibited in this work predicts higher productivity than every other model. The effectiveness got by utilizing the model in light of reflection gives essentially bring down esteem than the material-free model. The deformity free welds have been seen inside the scope of chose welding speeds. The effect of pulse duration, gas flow rate and focal position on process efficiency can also be tried and effective methods can be devised to measure efficiencies.

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