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Using ANN Approach to Investigate the Weld Geometry of Ti 6Al 4V Titanium Alloy

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***Abstract*—Nowadays Artificial Neural Networks (ANNs) are widely used for modeling and investigation the effects of process parameters. In the presented study, laser butt welding of Ti 6Al 4V material on a 2.2 Kw Co2 laser is investigated. The experiments were designed using a five level Response Surface Method (RSM). Effects of process parameters including laser power, welding speed and focal point position on butt weld geometries were carried out using Artificial Neural Network. Results indicate that the welding speed and laser power have significant effect, whereas, the focal point position show low effect on the process. The welding speed has an opposite effect on all responses while the laser power has a positive effect.**

***Index Terms*—Laser welding, Artificial Neural Network, Ti 6Al 4V**

I. INTRODUCTION

The high value of strength to weight ratio, good corrosion resistance and weld ability of titanium and its alloys have led to diverse application in various fields of industries including the medical, nuclear and aerospace.[1]

Among titanium alloys, Ti 6Al 4v with $\alpha+\beta$ phase is widely used. The strong chemical reactivity of titanium and its fast reaction and diffusion rates at high temperature result in difficulties with welding and differentiation titanium welding from other usual alloys. Lack of control in welding process leads to undesirable joint properties and also influences greatly the performance of the equipment [2].

Benyounis et al. proposed models using RSM to investigate the effect of welding parameters in SAW on the impact strength[3]. Optimization of friction welding of dissimilar materials using factorial design was studied by Murti and Sundaresan [4].

Li et al used a 6 Kw Co_2 laser for welding of titanium. Helium and Argon gases were used to prevent oxidation [5]. Properties and technical parameters of electron beam welding of commercial purity were investigated by Yunlian et al [6].

Casalino et al, investigated butt welding of Ti 6Al 4V alloy by using continuous Co_2 laser [7]. For a butt welding of Ti 6Al 4v alloy, Akman et al used a Nd:YAG laser. Pulse energy and pulse duration were considered as variables and other parameters (i.e repetition rate, welding speed, focal point position and gas pressure) assumed constant. Tensile strength, micro hardness and weld geometrical dimension were investigated [8]. To determine the effect of applying shielding protection with helium and argon gasses on titanium alloy using different nozzle designs, Caiazzo et al. have realized a study using CO2 laser [9].

In this study, the influence of process parameters (i.e., laser power, welding speed, focal point position) on bead geometry of the Ti6Al4V alloy has been investigated. Response surface method was used for experiment design. Twenty experiments were performed on the Ti6Al4V alloy butt-joint by using a 2.2 KW Co_2 laser machine. Finally, the neural network technique is used to model the laser welding process.

II. EXPERIMENTAL PROCEDURES

To investigate how process parameters affect on process state variables (i.e. butt weld geometries), twenty experiments were conducted. A central composite design including five levels of factors was employed. Laser power, welding speed and focal point position considered as independent input variables. To determine the working range levels of each variable, several preliminary experiments were conducted. Absence of visible welding defects and at least half depth penetration were the criteria of choosing the working ranges. Fig. 1 presents the bead shape and size of the selected sample. Table 1 shows laser input variables and experiment levels.

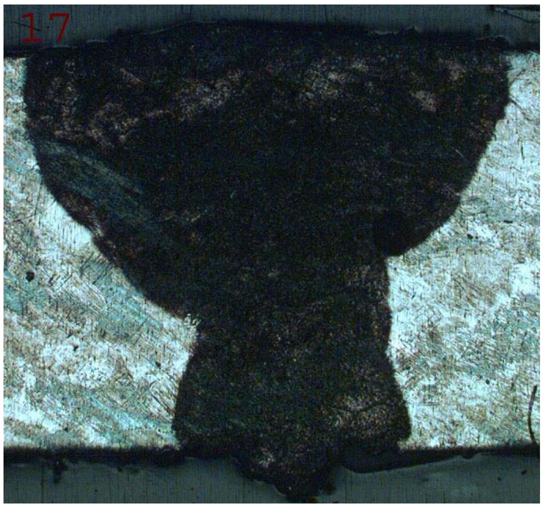


Fig.1 shows the bead shape, width and penetration depth of the selected sample

TABLE 1: LASER INPUT VARIABLE AND EXPERIMENTAL LEVELS

Parameter level (coded)	Laser Power (P) [W]	focal point position (F) [mm]	Welding speed (S) [cm/min]
-1.68	1200	-1	80
-1	1400	-0.8	145
0	1700	-0.5	240
1	2000	-0.2	335
1.68	2200	0	400

Ti 6Al 4V titanium alloy with chemical composition presented in Table 2 was used as work piece material. Samples were cut in dimension of 85 mm ×85 mm ×1.7mm (length, width and height respectively) and then the edges were grind using surface grinding machine to achieve a good joint. Experiments were conducted using an Optimo model CO_2 laser, provided by OPTIMA Industries.

TABLE 2: CHEMICAL COMPOSITION OF ALLOY TI 6AL 4V

elements	Titanium	Aluminum	vanadium
Weight percentage (Wt%)	90.02%	6%	3.98%

Argon gas with constant pressure of 0.1 bar was used as shielding gas. For performing metallography, each transverse section of specimens was mounted on an epoxy base. Etch solvent with the chemical composition of 2 ml HF+, 10 ml HNO_3+, 88 ml deionized H_2o was employed.

Welding geometrical parameters were measured using optical microscope and image analyzer software. The designed experiments are shown in Table 3.

TABLE 3: DESIGN MATRIX WITH INDEPENDENT CODED PROCESS VARIABLES

Run Order	Laser power [w]	Welding speed [cm/min]	Focal point position [mm]
1	-1.68	0	0
2	-1	-1	1
3	0	0	-1.68
4	1	1	-1
5	-1	1	-1
6	-1	1	1
7	0	0	0
8	0	0	0
9	0	0	0
10	1	-1	1
11	1	1	1
12	1.68	0	0
13	-1	-1	-1
14	0	1.68	0
15	0	0	1.68
16	0	0	0
17	0	-1.68	0
18	0	0	0
19	1	-1	-1
20	0	0	0

III. PROCESS MODELING AND DISCUSSION

Neural networks are one of the most proper tools in artificial intelligence which are widely used in industry applications. Twenty experimental data are used for laser welding modeling. Laser power, welding speed and focal point position were three parameters considered as network inputs. To have an accurate and reliable model, butt weld geometries (i.e., Penetration depth, Welding zone width and Heat affected zone width) are separately estimated by using a Perceptron neural network. Several network architectures, which are not presented in this study, are tested. The appropriate architecture with one hidden layer is selected, 3×2×1. Results are presented and discussed in the following sections.

The geometry of weld bead was measured in accordance with parameter setting shown in Table 3. In conclusion, the welding speed and laser power are most effective parameters, whereas, the focal point position is less effective one.

A. *Effects of process variables*

1) *Penetration depth (Pd)*

As shown in Fig.2, the welding speed and laser power affect significantly the penetration depth. The increase of laser power increases the heat input. Therefore, more molten materials and consequently more penetration depth are achieved. However, the idea is reversed in the case of welding speed effect, because the welding speed matches an opposite with the heat input.

To obtain the maximum penetration depth, the laser power has to be maximized and welding speed has to be minimized during welding process. The maximum and minimum values of penetration depth are shown in Table 4.

TABLE 4: MAXIMUM AND MINIMUM VALUES OF PENETRATION DEPTH

Power [w]	Welding speed [cm/min]	Focal position [mm]	Penetration depth (Pd) [mm]
1200	240	-0.5	0.46
1700	240	-0.5	1.7

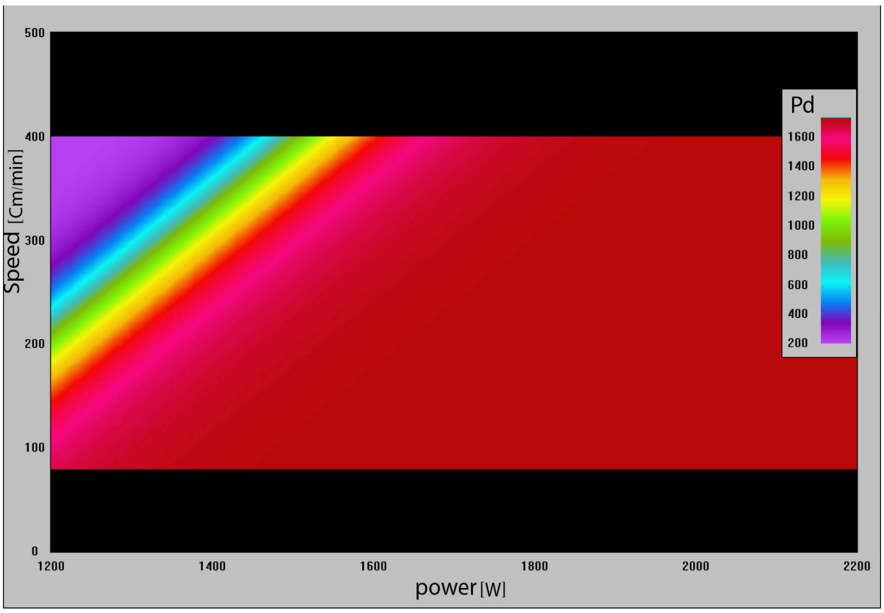


Fig. 2-a: Effects of laser power and welding speed on the penetration depth

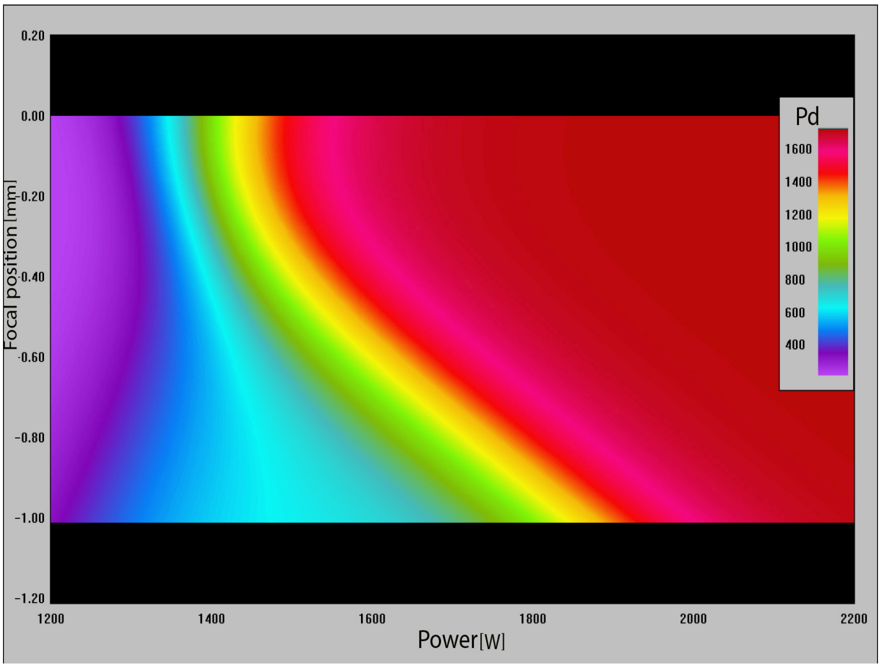


Fig. 2-b: Effects of laser power and focal point position on the penetration depth

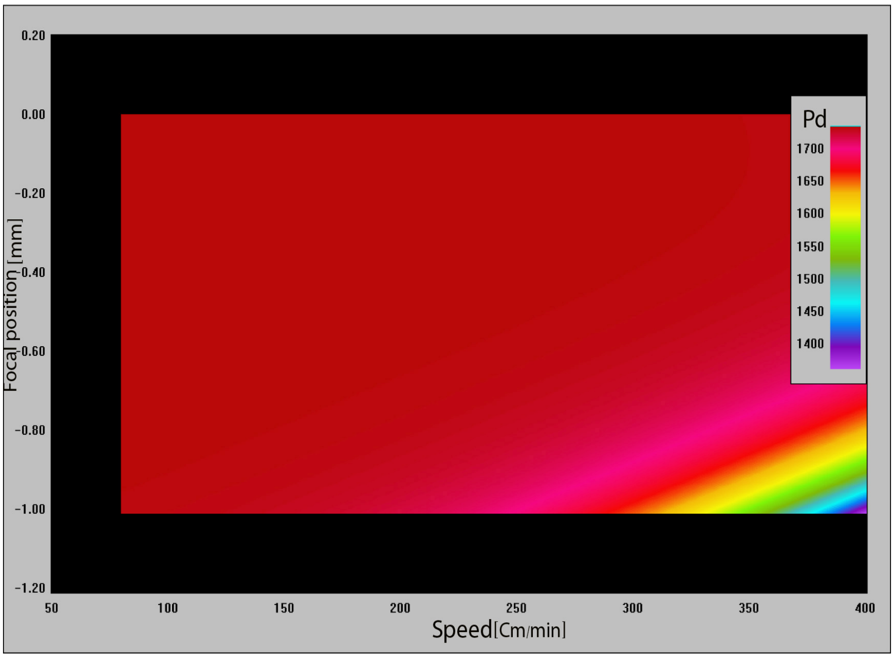


Fig. 2-c: Effects of welding speed and focal point position on the penetration depth

Fig. 2: Effects of process factors on the penetration depth

2) Welding zone width (Wfz)

As shown in Fig. 3, the welding speed and laser power have demonstrated the most influence on welding zone width. The width of welding zone is decreased with increasing the speed of welding and laser beam. The width of welding zone is increased with increasing the laser power. It is as a result of the increased input heat. The maximum and minimum values of welding zone width are shown in Table 5.

TABLE 5: MAXIMUM AND MINIMUM VALUES OF WELDING ZONE WIDTH

Power [w]	Welding speed [cm/min]	Focal position [mm]	Welding zone width [mm]
1403	335	-0.2	1.063
1700	80	-0.5	2.685

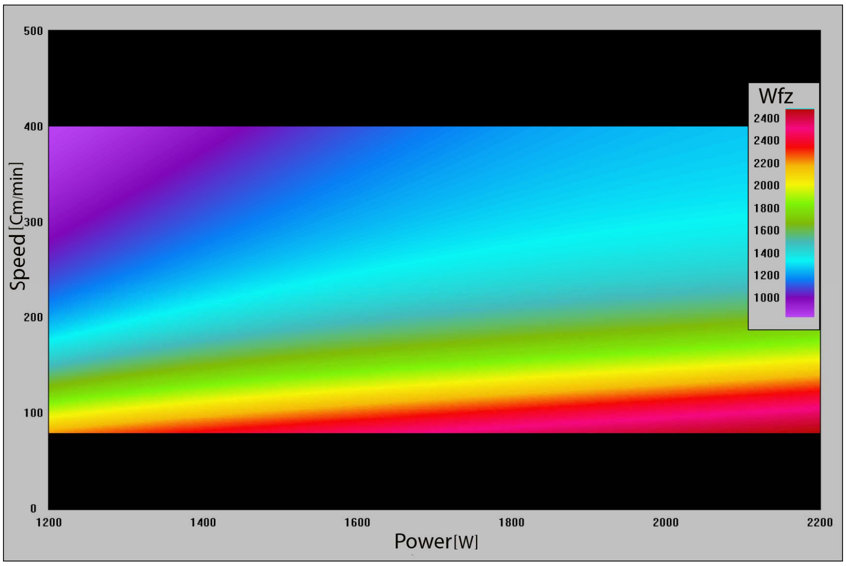


Fig. 3-a: Effects of laser power and welding speed on the welded zone width

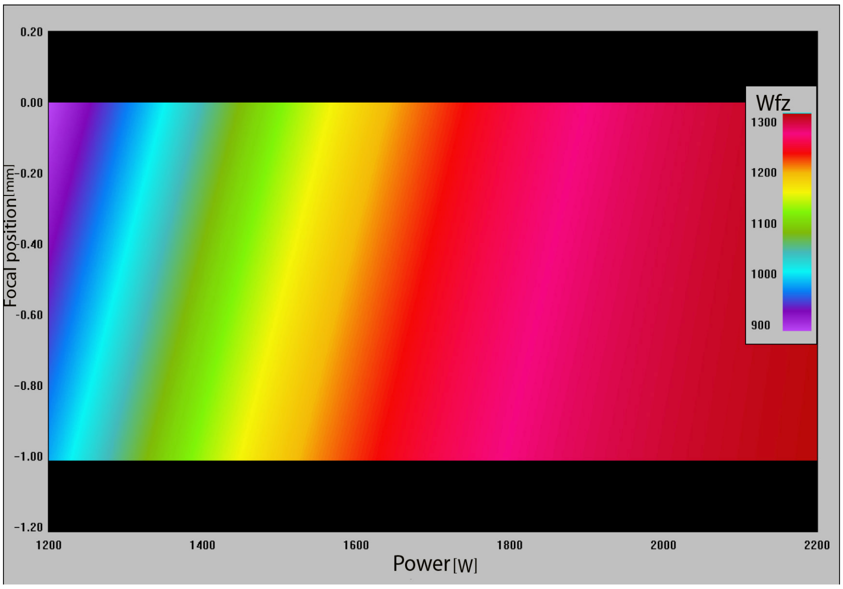


Fig. 3-b: Effects of laser power and focal point position on the welded zone width

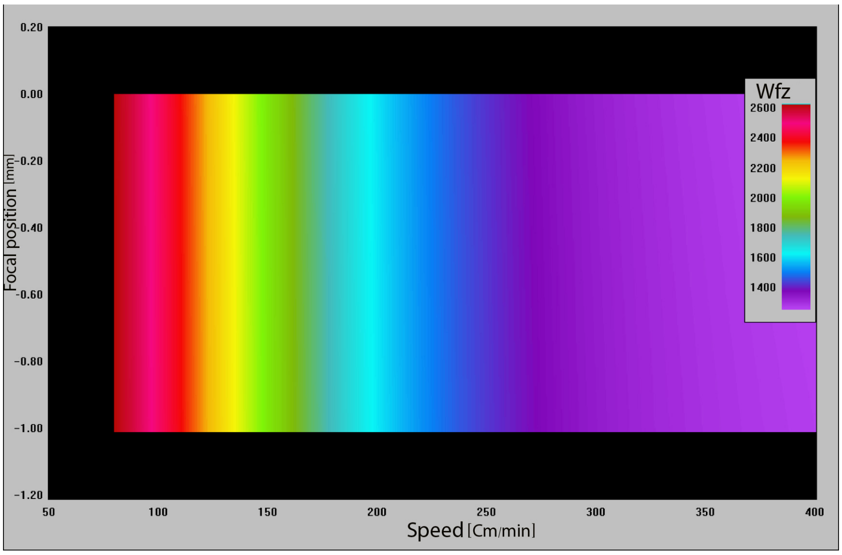


Fig. 3-c: Effects of welding speed and focal point position on the welded zone width

Fig. 3: Effects of process factors on the welded zone width

3) Heat affected zone width (Whaz)

The heat of welding process significantly affects the heat affected zone and metallurgical structure of work piece.

Also, the welding speed and laser power affect significantly the HAZ width (see Fig.4). The increase of Welding speed results a decrease in HAZ width. On the contrary, HAZ width increases with increasing the laser power and with decreasing the welding speed. It is due to the increased heat input and so, more volume of melted metal.

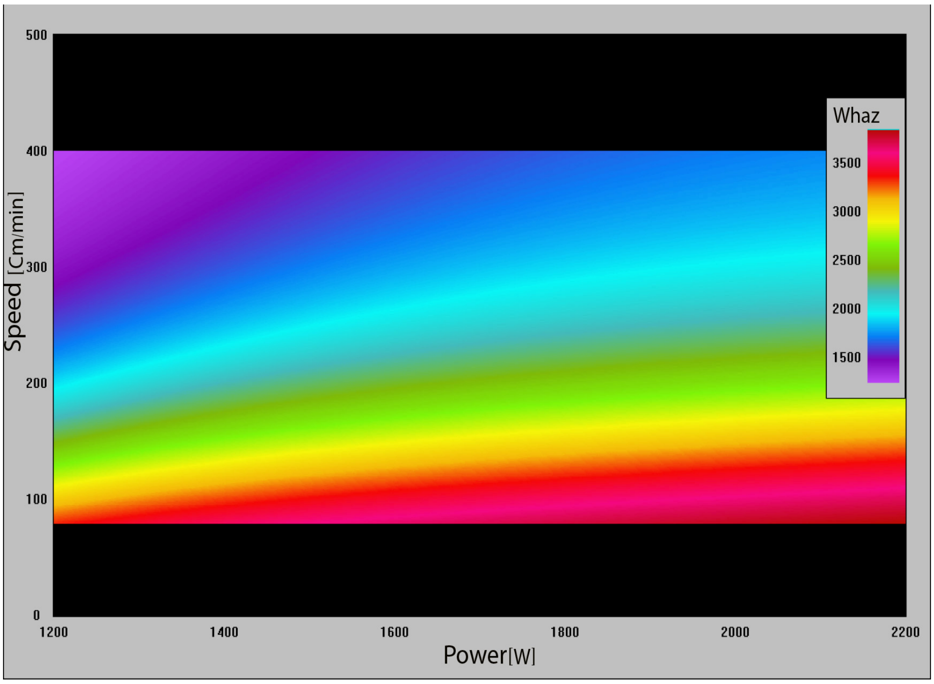


Fig. 4-a: Effects of laser power and welding speed on the heat affected zone width

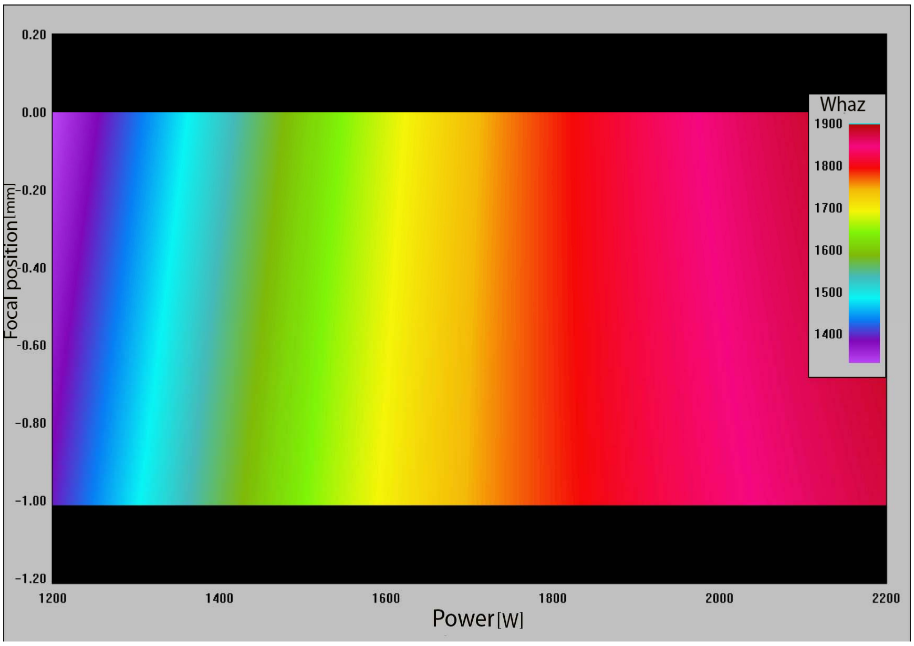


Fig. 4-b: Effects of laser power and focal point position on the heat affected zone width

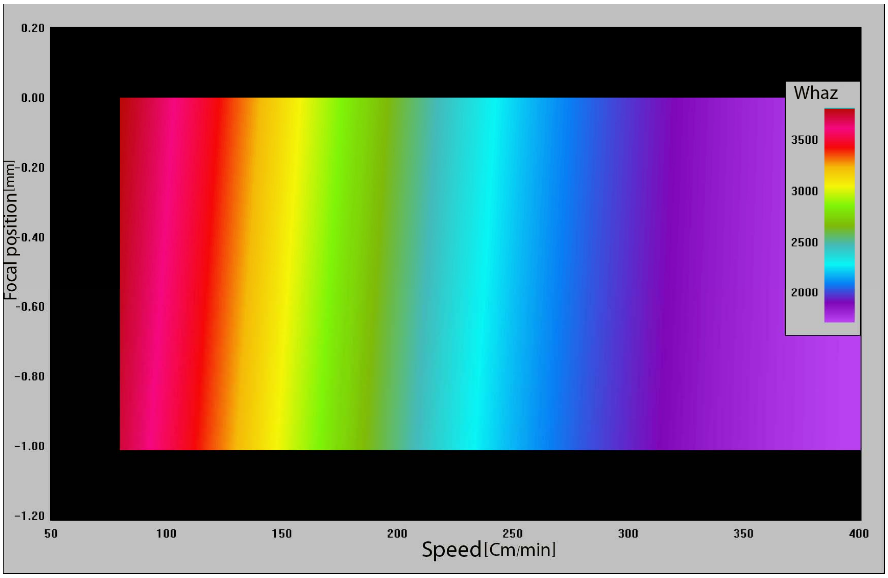


Fig. 4-c: Effects of welding speed and focal point position on the heat affected zone width

Fig. 4: Effects of process factors on the heat affected zone width

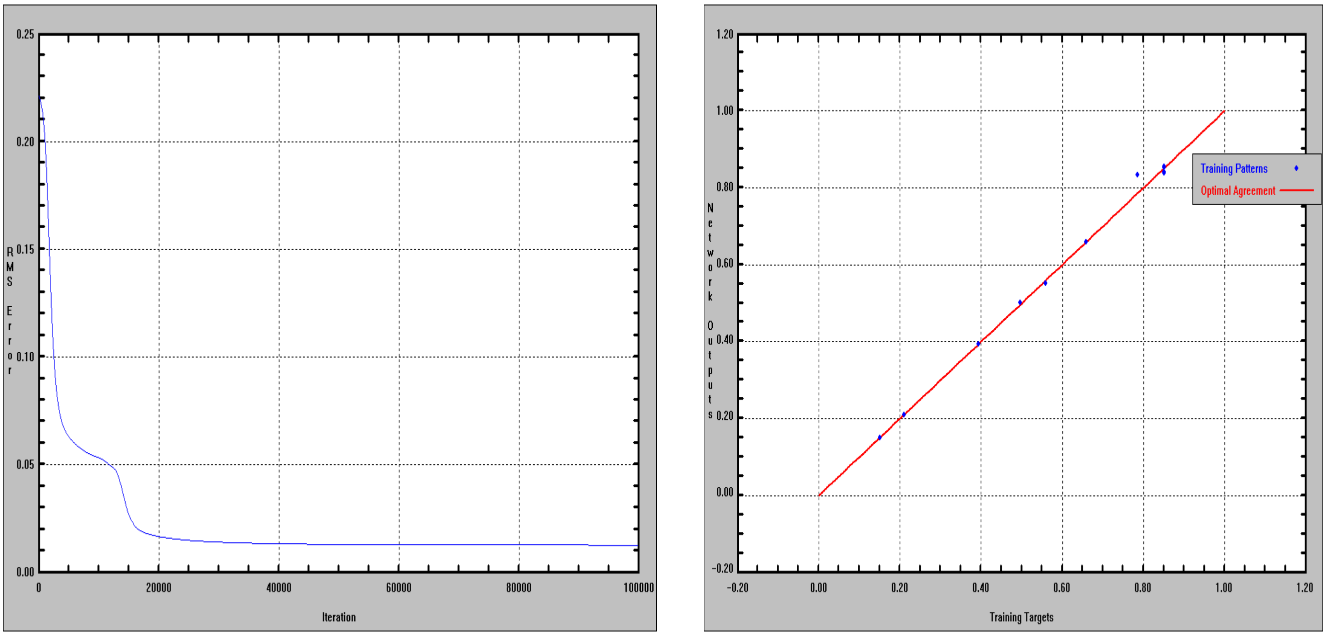
B. *Validation of proposed models*

Many tools are available for testing the modeling capacity. In this study, RMS error and Targets/Network outputs plots are used for checking the performance of the proposed models.

Figs 5 to 7 show RMS error and Targets/Network outputs plots of the proposed neural models, (i.e., Penetration depth, Welding zone width and Heat affected zone width models).

About 0.02 RMS error is seen in the modeling of the penetration depth, HAZ width and welding zone width. It is apparent that the less the error value results the more accurate model (see Figs 5a to 7a).

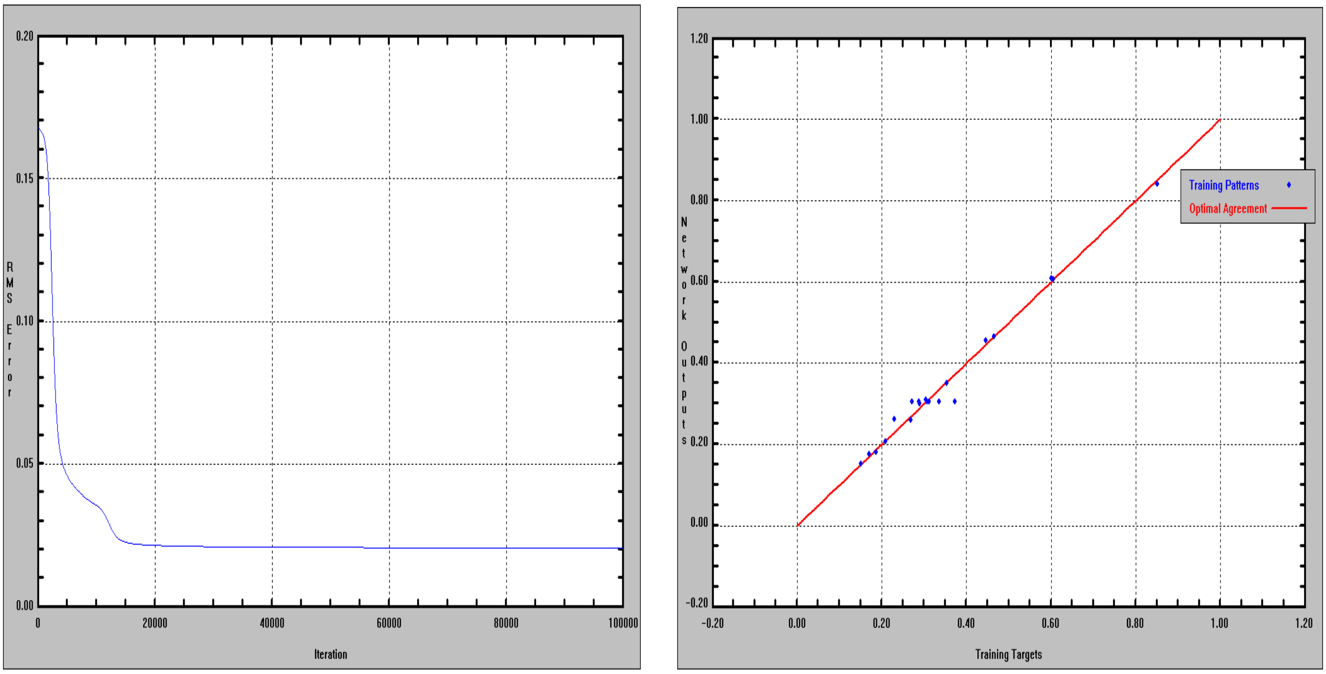
As shown in Figs 5b to 7b, the residuals are appropriately distributed around "X=Y" line .The closer the points fall to the "X=Y" line, the stronger the model.



(a) (b)

Fig.5: a) RMS error plot of penetration depth

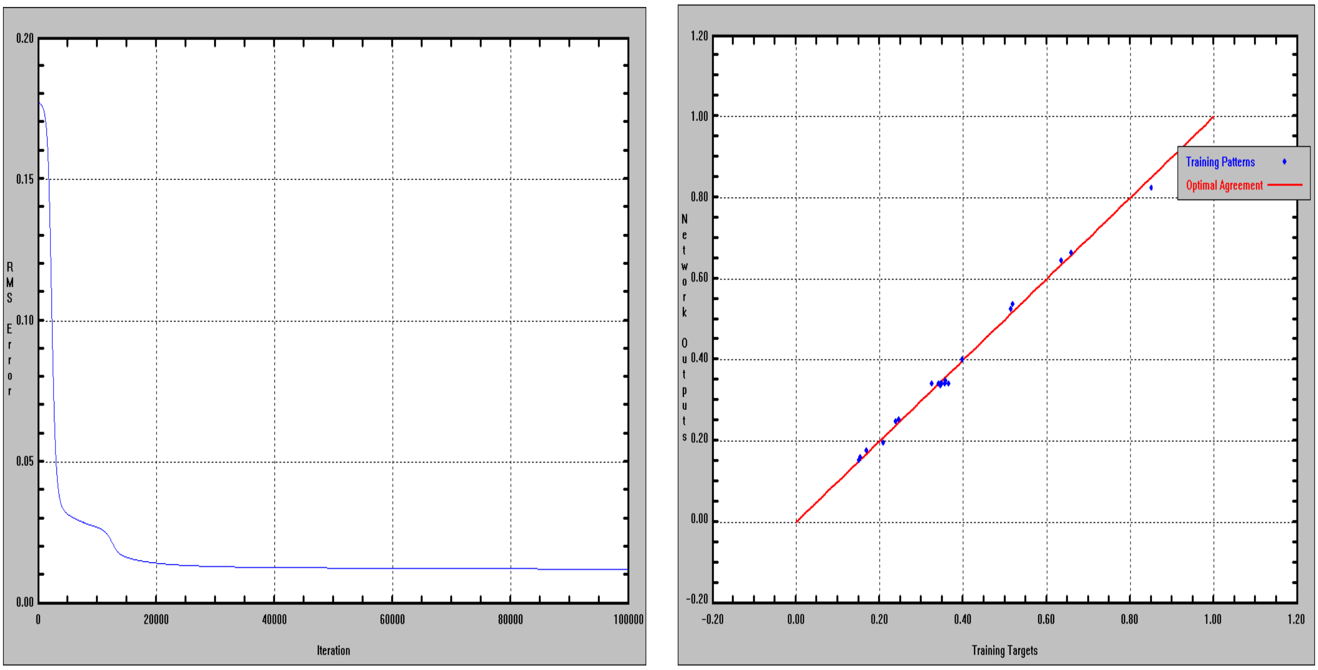
b) Targets/Network Outputs plot of penetration depth



(a) (b)

Fig.6: a) RMS error plot of welded zone width

b) Targets/Network Outputs plot of welded zone width



(a) (b)

Fig. 7: a) RMS error plot of Heat affected zone width
b) Targets/Network Outputs plot of heat affected zone width

Furthermore, to evaluate the modeling capacity of the proposed models, five other experiments were conducted. Bead geometry was measured using optical microscope and image analyzer software. The obtained results have shown the accuracy of the models for laser welding process modeling (see Table 6)

TABLE 6: EVALUATION RESULTS

Models	Accordance Ratio
Penetration depth	91%
Welding Zone width	99%
Heat affected Zone width	96%

V. CONCLUSION

In this study, the laser butt welding of Ti 6Al 4V on a 2.2 Kw Co_2 laser is investigated. The effects of process parameters including the laser power, welding speed and focal point position on butt weld geometries are carried out by using the artificial neural network. The conclusions are as follows,

- Focal point position has low effect on process outputs.
- Welding speed and laser power are most significant factors in welding process. The laser power has a positive effect on all responses whereas the welding speed adversary affect.
- Proposed neural network has demonstrated the very appropriate modeling capacity with average accordance ratio of 95.3%.

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