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การศึกษาหาค่าการติดตั้งที่เหมาะสมสำหรับเครื่องจักรเชื่อมอัตโนมัติ: กรณีศึกษาชิ้นส่วนเครื่องบิน

Determining Appropriate Settings for Automatic TIG Welding Machine: A Case Study of Aviation Component

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บทคัดย่อ

งานวิจัยนี้เป็นการศึกษาหาค่าที่เหมาะสมของปัจจัยที่สำคัญในกระบวนการเชื่อมทิกสำหรับชิ้นส่วนเครื่องบิน โดยปัจจัยที่เกี่ยวข้องในการศึกษาประกอบด้วย กระแสไฟในการเชื่อม อัตราการป้อนลวด ความเร็วในการเชื่อมและเวลาหน่วง ผลตอบสนอง คือ จำนวนจุดของการแตกร้าวและจำนวนช่องว่างที่เกิดขึ้น โดยจากการออกแบบการทดลองเพื่อกรองปัจจัย พบว่า ด้วยระดับนัยสำคัญที่ 0.05 ปัจจัยที่มีผลต่อการเชื่อมอย่างมีนัยสำคัญ คือ กระแสไฟในการเชื่อม อัตราการป้อนลวด และความเร็วในการเชื่อม หลังจากนั้นจึงได้ทำการออกแบบการทดลองเชิงแฟกทอเรียลแบบเต็มจำนวนและการออกแบบการทดลองแบบบ็อกซ์เบห์นเคน โดยกำหนดให้แต่ละปัจจัยมีทั้งสิ้น 3 ระดับ ซึ่งจากการศึกษาพบว่าด้วยระดับนัยสำคัญที่ 0.05 ค่าที่เหมาะสมของกระแสไฟในการเชื่อมเท่ากับ 18 แอมป์ ค่าที่เหมาะสมของอัตราการป้อนลวดเท่ากับ 28 นิ้วต่อนาที และค่าที่เหมาะสมของความเร็วในการเชื่อมเท่ากับ 2.4 นิ้วต่อนาที และจากผลการทดลอง พบว่า การกำหนดค่าปัจจัยดังกล่าวทำให้ไม่พบการแตกร้าวและช่องว่างในการเชื่อม

คำสำคัญ: การเชื่อมทิก บ็อกซ์เบห์นเคน พื้นที่การตอบสนอง การออกแบบการทดลอง

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ABSTRACT

This research is to determine the appropriate settings of significant factors in automatic TIG welding for aviation component. The considered parameters in TIG welding include welding current, welding feed rate, welding speed, and delay time. The response is the number of cracks and porosity. Based on the experiments, welding current, welding feed rate, and welding speed are significant parameters with the significant level of 0.05. Then, a Box-Behnken experiment with 3 levels for each parameter is designed. The study shows that with the significant level of 0.05, the appropriate settings of welding speed, feed rate, and welding current are 2.4 inch/minute, 28 inch/minute, and 18 amp, respectively. The result shows that with the appropriate settings, there is no crack and porosity.

Keywords: TIG welding, Box-Behnken, Response Surface Optimization, Design of Experiment

Introduction

The aviation component considered here is HPC blade stage 2 (Fig. 1). After HPC blades are used for a while, they are deteriorated. Currently, TIG welding process is the repairing process of HPC blade stage 2, which is made of Titanium. Based on the case study, it was found that the percentage of rework units is quite high (12%) and the TIG welding process is the main cause of the problem.

TIG welding, standing for Tungsten Inert Gas welding, is a commonly used high quality welding process. TIG welding has become a popular choice of welding processes when high quality and precision welding is required. In TIG welding, an arc is formed between a non-consumable tungsten electrode and the metal being welded. Gas is fed through the torch to shield the electrode and molten weld pool. If filler wire is used, it is added to the weld pool separately as Fig 2 [1]. This research uses an automatic TIG welding machine, which is a welding equipment performing the welding operations without adjustment of the controls to repair the HPC blade stage 2. Fig. 3 shows the seven sections of the HPC blade stage 2 and this research gives the consideration of the 6th section. In this research, appropriate settings of automatic TIG welding are determined by using design of experiments approach.

Figure 1: HPC Blade Stage 2

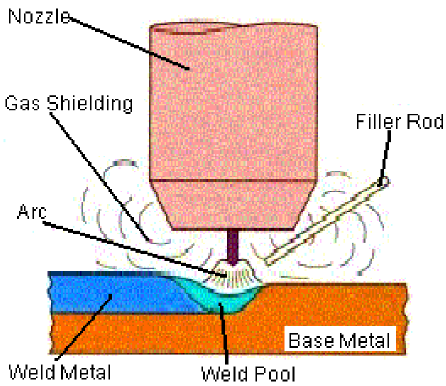

Figure 2: TIG Welding Method

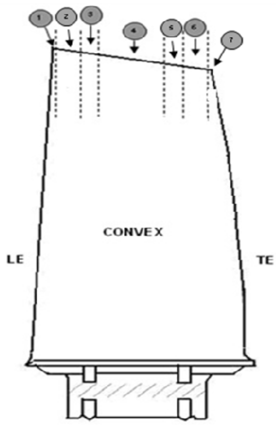

Figure 3: HPC Blade Stage 2's Diagram Divide into Seven Sections

Process review

Aviation repairing process of HPC Blade Stage 2 is shown in Fig 4. Parts which are serviceable after inspection will be released to the welding process. After passing the welding process, parts are blended to an appropriate size. Then an inspection is given to the blended parts. X-Ray is used to detect defective units. In case of having cracks or porosities, the parts are sent back to the welding process to rework. In the other case, parts are sent to the process of heat treatment.

This research gave the consideration in the welding process, blending process, and X-ray only. Since to identify whether the welding process settings are appropriate or not, X-ray inspection process is required. X-ray inspection process would use to show if there is a crack or porosity in the welded parts. If there is no crack or porosity in the welded parts, the parts are good. Contrarily, the parts are defective and needed to be reworked.

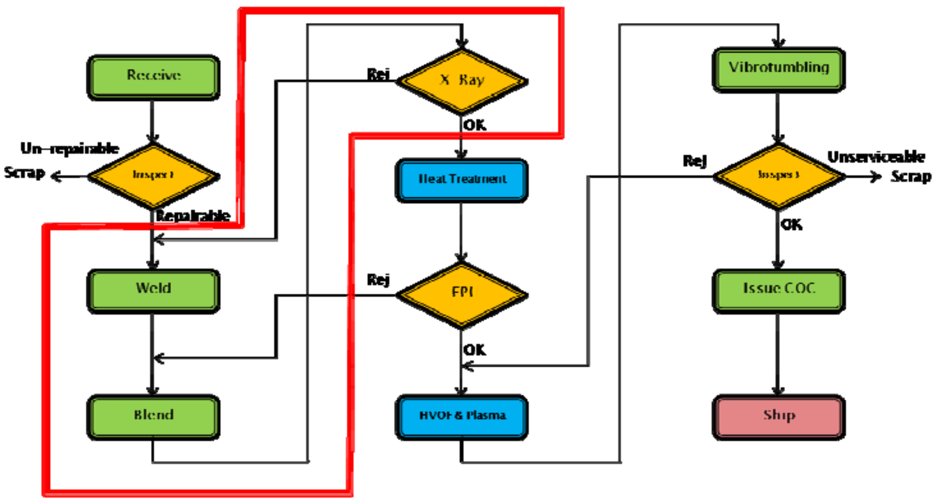

Figure 4: Process review

Parameters

Control parameters of automatic TIG welding machine are welding speed, feed rate, welding current and welding delay [2]. Welding speed is a very important parameter because of its effect on costs. In some applications, welding speed is defined as an objective, with the other variables selected to achieve the desired weld configuration at that speed. In other cases, welding speed might be a dependent variable selected to obtain the weld quality and uniformity needed under the best conditions possible with the other combination of variable.

In automatic welding, wire feed speed determines the amount of filler per unit length of weld in one minute. Decreasing wire feed speed will increase penetration and flatten the bead contour. Feeding the wire too slowly can lead to undercut, centreline cracking, and lack of joint fill. Increasing wire feed speed decreases weld penetration and produces a more convex weld bead. Hence, feed rate is a significant parameter.

Welding current is a source of arc between tungsten and weld metal. The deep of welding pool can be controlled by adjusting welding current. Too much current value can lead undercut or crack but if welding current is too less, weld wire may not be melted and jointed to welding metal.

The last parameter is welding delay between welding positions. Normally this parameter will be adjusted by welder who is specialist in automatic welding. Welder believes that there is some heat collection in the process of welding; delay time may reduce the effect of heat collection before starting the next position.

Although there are many conditions for setting the automatic welding, such as voltage, shield gas, a welding distance, and the angle of welding torque but these conditions were fixed at the specific standard performance of the machine. Thus four parameters which are welding speed, feed rate, welding current and delay time would be studied in automatic welding machine. The design and analysis of experiments for the study are shown in the next section.

Design and analysis of experiments

First, four selected parameters including welding speed, feed rate, welding current, and delay time, have to be determined whether they are significant. Two levels for each parameter are defined as shown in Table 1. The experiment had been done with two replications. Hence, 2^4 *2 equally 32 experiments have been completed. Table 2 and Fig. 5 show the result generated by Minitab release version 14. Based on the result, with the significant level of 0.05, only the interaction welding speed and feed rate, and the interaction of welding speed and welding current are significant. Therefore, welding speed, feed rate, and welding current affect to the number of defects. Only delay time does not significantly affect to the number of defects.

Then Box-Behnken design and experiment approach is used to determine appropriate settings of welding speed, feed rate, and welding current, while setting delay time as 0.15 seconds. 15 experiments have been designed by Box-Behnken design and experiment approach (Table 3) and 5 replications are used. So, the total experiments, which are 75 experiments, have been done. The results generated by Minitab release version 14 are shown in Tables 4-5. Moreover, Figs. 8-9 show that the data are normally distributed. The model generated in Tables 4-5 are used to determine the optimize values of parameter settings by using Response Surface Optimization. The results show in Table 6 and Figs. 10-11. It can be seen that by using minimization as an objective function, the optimum parameter settings are: welding speed=2.4 inch/minute, feed rate= 27.98 inch/minute and welding current=17.93 amp.

Table 1: Input welding parameters and their ranges

Parameter/Unit	Level		Code
	Low (-1)	High (+1)	
1. Welding Speed (Inch/min)	2.0	2.2	A
2. Feed Rate (Inch/min)	22	26	B
3. Welding Current (Amp)	18	19	C
4. Delay Time (Sec)	0.15	0.2	D

Table 2: Analysis of variance for screening parameter

Term	Effect	Coef	SE Coef	T	P
Constant		0.2813	0.06988	4.02	0.001
A	0.0625	0.0313	0.06988	0.45	0.661
B	0.1875	0.0937	0.06988	1.34	0.198
C	0.1875	0.0938	0.06988	1.34	0.198
D	-0.0625	-0.0313	0.06988	-0.45	0.661

A*B	**-0.3125**	**-0.1563**	**0.06988**	**-2.24**	**0.040**
A*C	**0.4375**	**0.2187**	**0.06988**	**3.13**	**0.006**
A*D	-0.0625	-0.0312	0.06988	-0.45	0.661
B*C	-0.1875	-0.0937	0.06988	-1.34	0.198
B*D	0.0625	0.0312	0.06988	0.45	0.661
C*D	0.0625	0.0313	0.06988	0.45	0.661
A*B*C	0.0625	0.0313	0.06988	0.45	0.661
A*B*D	0.0625	0.0312	0.06988	0.45	0.661
A*C*D	-0.1875	-0.0938	0.06988	-1.34	0.198
B*C*D	0.1875	0.0937	0.06988	1.34	0.198
A*B*C*D	-0.0625	-0.0312	0.06988	-0.45	0.661

Analysis of Variance for Result (coded units)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	0.62500	0.62500	0.15625	1.0000	0.436
2-Way Interactions	**6**	**2.68750**	**2.68750**	**0.44792**	**2.87000**	**0.043**
3-Way Interactions	4	0.62500	0.62500	0.15625	1.0000	0.436
4-Way Interactions	1	0.03125	0.03125	0.03125	0.2000	0.661
Residual Error	16	2.50000	2.50000	0.15625		
Pure Error	16	2.50000	2.50000	0.15625		
Total	31	6.46875				

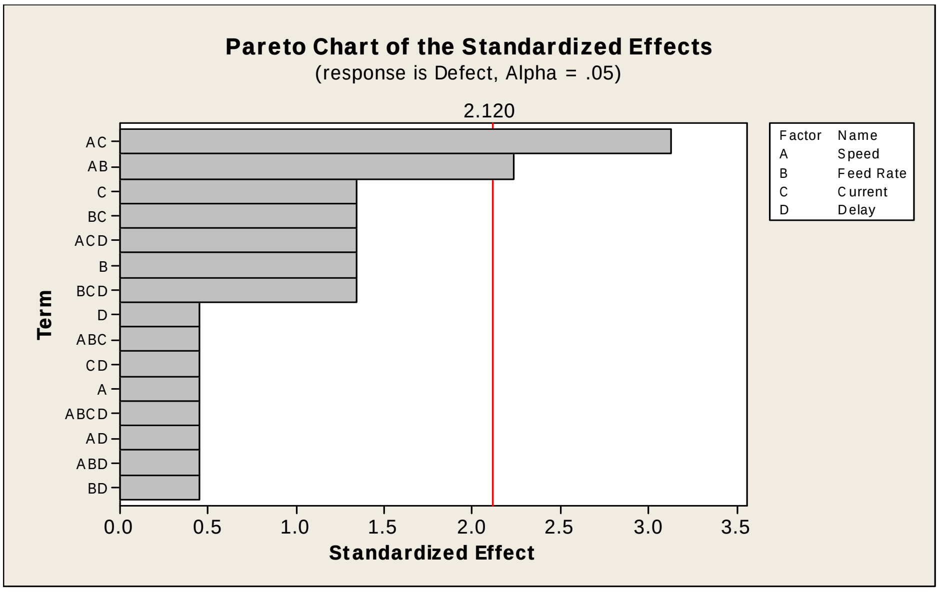

Figure 5: Pareto chart of the standard effects

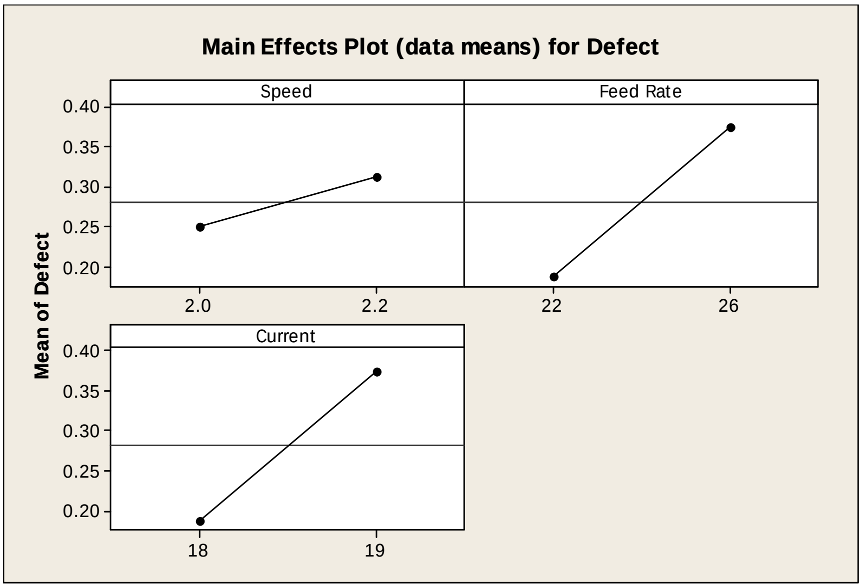

Figure 6: Main effect plot

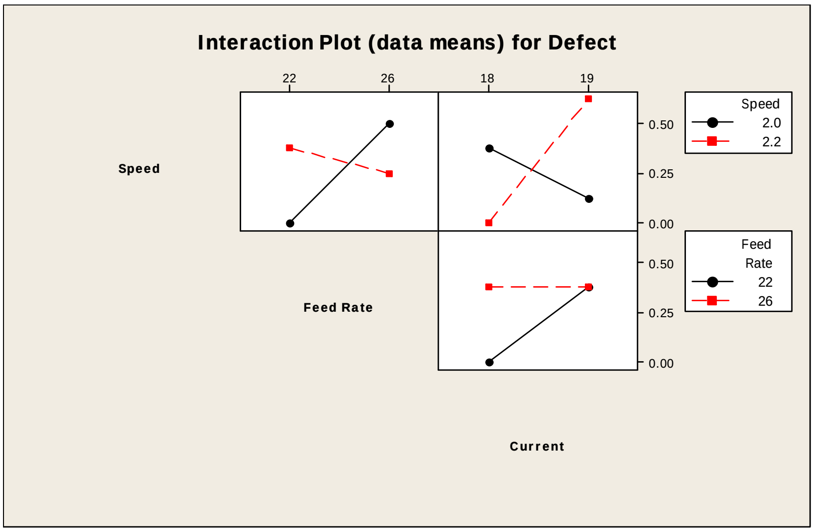

Figure 7: Interaction plot

Table 3: Process variables of Box-Behnken experiment

Parameter/Unit	Level			Code
	Low (-1)	Medium (0)	High (+1)	
1. Welding Speed (Inch/min)	2.0	2.2	2.4	A
2. Feed Rate (Inch/min)	22	25	28	B
3. Welding Current (Amp)	17	18	19	C
4. Delay Time = 0.15 sec				

Table 4: Response surface regression

Response Surface Regression: Defect versus Speed, Feed Rate, Current

The analysis was done using uncoded units.

Estimated Regression Coefficients for defect

Term	Coef	SE Coef	T	P
Constant	56.2769	42.7363	1.317	0.193
A	30.6250	13.9268	2.199	0.031
B	-0.9981	0.8371	-1.192	0.237
C	-8.7583	3.6709	-2.386	0.020
A*A	-3.9583	2.3918	-1.655	0.103
B*B	0.0213	0.0106	2.003	0.049
C*C	0.2417	0.0957	2.526	0.014
A*B	-0.3333	0.1532	-2.176	0.033
A*C	-0.2500	0.4596	-0.544	0.588
B*C	0.0333	0.0306	1.088	0.281

Table 5: Analysis of variance

Analysis of Variance for Defect

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	7.203	7.203	0.8004	4.74	0.000
Linear	3	3.850	2.474	0.8246	4.88	0.004
Square	3	2.303	2.303	0.7678	4.54	0.006
Interaction	3	1.050	1.050	0.3500	2.07	0.113
Residual Error	65	10.983	10.983	0.1690		
Lack-of-Fit	3	1.250	1.250	0.4167	2.65	0.056
Pure Error	62	9.733	9.733	0.1570		

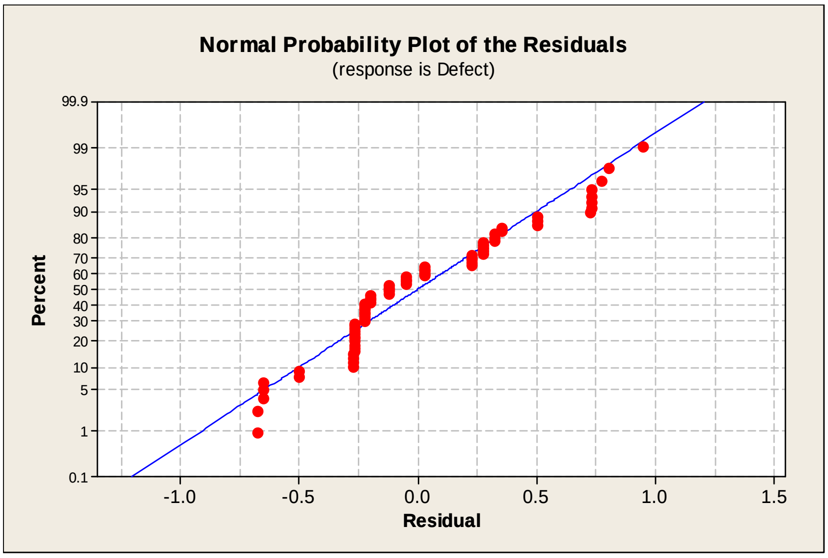

Figure 8: Normal probability plot of the residuals

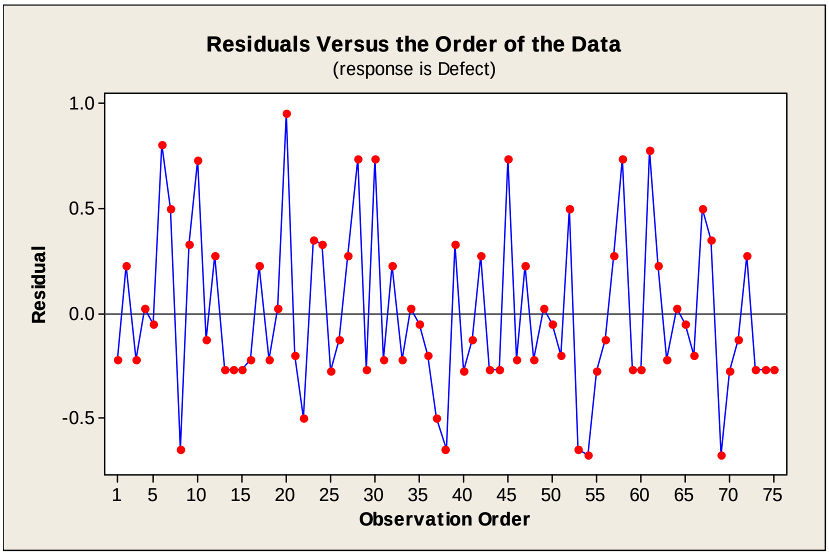

Figure 9: Residuals plot of the data

Table 6: Response optimization parameters

Response Optimization Parameters

	Goal	Lower	Target	Upper	Weight	Import
Defect	Minimum	0	0	0.01	1	1

Global Solution

Speed	2.4000
Feed Rate	27.9804
Current	17.9280

Predicted Responses

Defect = -0.03983, desirability = 1

Composite Desirability = 1.00000

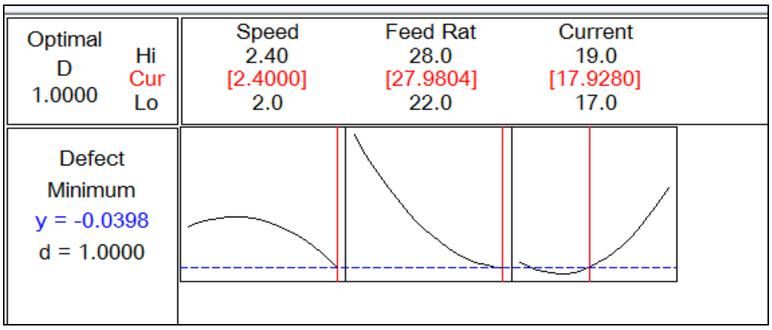

Figure 10: Graph of optimization parameters

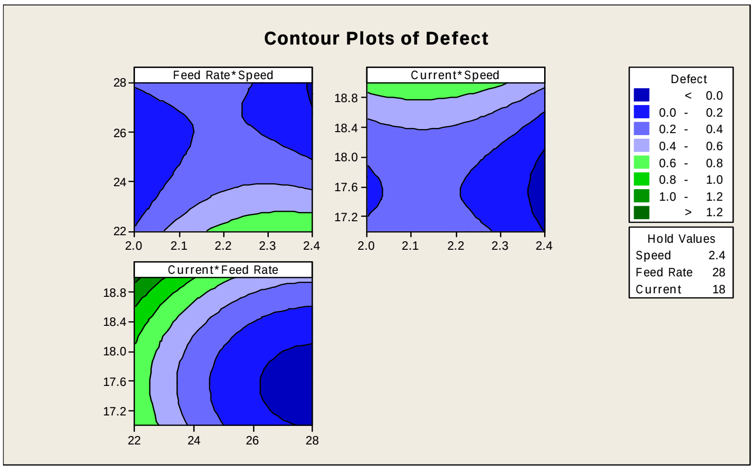

Figure 11: Contour plots

Conclusions and recommendations

By using design and analysis of experiment to determine appropriate parameter settings of HPC Blade stage 2 in an automatic welding machine, it is found that welding speed=2.4 inch/min, feed rate= 27.98 inch/min, and welding current=17.93 amp. To apply to the automatic welding machine, the parameters need to be rounded. Welding speed is 2.4 inch/min. Feed rate is 28 inch/min. Welding current is 18 amp. These settings are tested totally 207 pieces in order to confirm the result. The result shows that there is no defective unit.

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