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Process Parameters Optimization using Kuhn-Tucker Conditions For Plasma Arc Welding Using Austenitic Stainless Steel Alloy-304l Plates

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Abstract*: This paper is intended to evaluate the process parameters and decision variables for framing an optimization function to make the welding of Austenitic stainless steel alloy-304L plates more reliable. This is made by finding the decision variables involved in the welding operation. It is always important for the process to be done effectively and efficiently. The present work evaluates various parameters involved in plasma arc welding, then were analyzed critically with respect to their boundary conditions. Then the optimization function is formulated, there after the constraints involved in making the welding process were found and also the conditions were defined. Next optimization of this objective function is done by appropriate methods. Here in this case the objective function involved multiple number of decision variables and also it has got mixed type of constraints. Hence in order to solve such problem Kuhn- tucker method is applied. And at the end the optimal values for the decision variables were found. By adapting these set of values in the welding the process got optimized.

Keywords: Welding, Optimization, Kuhn-tucker conditions.

I. INTRODUCTION

The plasma arc welding is a special purpose welding operation for better accuracy and precision. It has been considered for the welding to high end applications for the better strength. But during the process the machine has failed many times due to various problems. Hence all the failures have refined and quantified for the assessment and optimization. On the other hand the work piece that is used for welding is austenitic stainless steel alloy-304L. Basically this material is of moderate hardness and moderate strength with a annealed crystal structure. The general tendency of the material should not get distracted because of the operation to be imposed on it. This got analyzed by considering the response of the material in terms of surface roughness, surface hardness and changes in micro structure.[1]

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Often it is observed that for a period of about 20-45% of operating time of weld it the process has yielded the best results like a youth age in a bath tub curve. The above quantified data has been considered as the boundary conditions for the operation of welding and the corresponding parameters were optimized. This has been illustrated with the below flow chart.

II. ANALYSIS

Machine: Here in this part the analysis of the above mentioned methodology is carried out. And as it has two things to consider viz., The machine and the work piece each of these will be analyzed one after another. The failure data of the machine is considered based on the following assumptions. They are:

1. The machine run time in a cycle is limited to 3 hours and the gap between each cycle is taken as 30 minutes. In a day the maximum permissible working hours are 3 cycles that are 9 hours a day.
2. During the cycle operation time the machine subjected different types of hazards and they are quantified based on the operating times and failures times. This process is continued for a period of three six months.
3. The environmental and human fatigue is not considered as the failures.

As it is known from the reliability fundamentals and machine life cycle, the time between failures and time to repair were analyzed and the trend of failures is found. The tests used here for the trend analysis are Cumulative plot test, Eye ball test, Karl pearson test with (i=1), Karl pearson test with (i=2) and Serial correlation tests of (i=1) and (i=2). Based on the above mentioned four tests the majority that is four out six results were taken as the results. As the above mentioned methods involve both graphical and analytical results the accurate results will be obtained. The same method is carried out for the time between failure data and time to repair data. Hence the reliability and availability will be obtained.[2] The below figure (Fig 1) shows the methodology of the process that was carried out. The below table (Table 1) depicts the outcomes of the various tests and their verdicts. The first table indicates the data of time between failures and the second table depicts the outcomes pertaining to the time to repair.

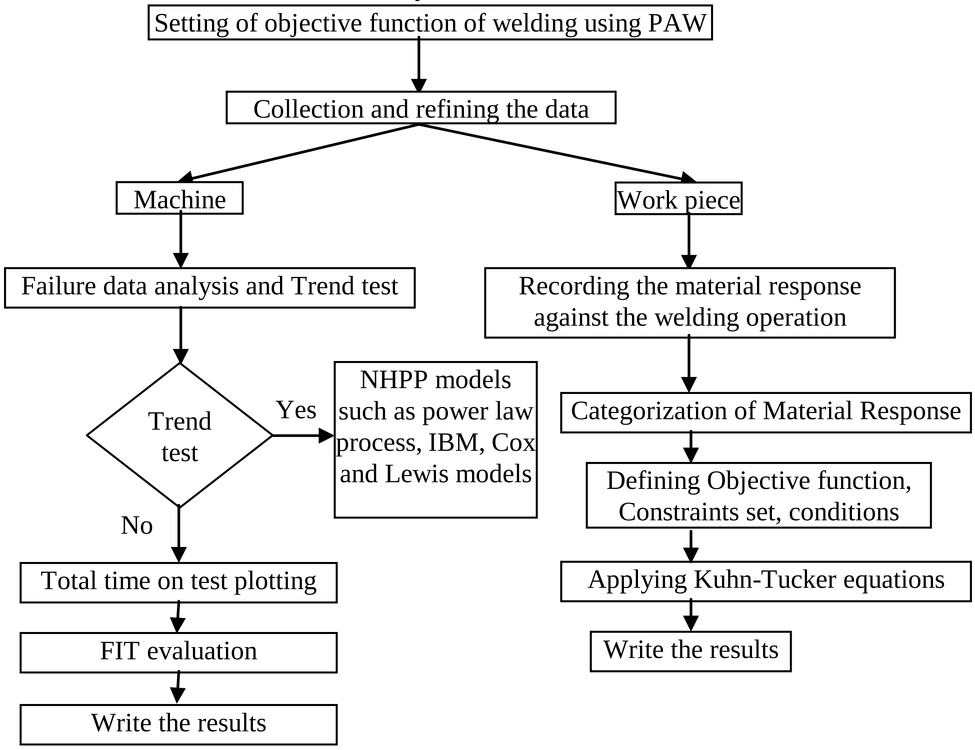

Figure 1 : Flow chart of Process Parameters Optimization Using Kuhn-Tucker Conditions for Plasma Arc Welding Using Austenitic Stainless Steel Alloy-304L Plates

Table I: List of results based on Time between failures and Time to repair with 6 tests.

TBF based							
Item	**Cumulative Plot Test**	**Eye Ball Test**	**Karl Pearson (i-1)**	**Karl Pearson (i-2)**	**Serial Correlation (i) vs (i-1)**	**Serial Correlation (i-1) vs (i-2)**	**Result**
Aug 2018	Weak - ve Trend	+ ve Trend	+ ve Trend	+ ve Trend	+ ve Trend	Weak + ve Trend	+ ve Trend
Sep 2018	+ ve Trend	Weak + ve Trend	Weak + ve Trend	Weak + ve Trend	Weak + ve Trend	+ ve Trend	+ ve Trend
Oct 2018	Weak + ve Trend	Weak - ve Trend	Weak + ve Trend	Weak + ve Trend	Weak + ve Trend	Very Weak + ve Trend	+ ve Trend
Nov 2018	Weak - ve Trend	Weak + ve Trend	Weak –ve trend	Weak + ve Trend	+ ve Trend	+ ve Trend	+ ve Trend
Dec 2018	Weak - ve Trend	Weak + ve Trend	Weak - ve Trend	Weak + ve Trend	Weak - ve Trend	very Weak - ve Trend	- ve Trend
Jan 2019	Weak + ve Trend	Weak - ve Trend	Weak + ve Trend	Weak - ve Trend	No Trend	Weak - ve Trend	+ ve Trend
TTR based							
Item	**Cumulative Plot Test**	**Eye Ball Test**	**Karl Pearson (i-1)**	**Karl Pearson (i-2)**	**Serial Correlation (i) vs (i-1)**	**Serial Correlation (i-1) vs (i-2)**	**Result**
Aug 2018	Weak + ve Trend	Weak + ve Trend	Weak - ve Trend	Weak - ve Trend	Weak - ve Trend	- ve Trend	- ve Trend
Sep 2018	- ve Trend	Weak - ve Trend	Weak - ve Trend	Weak - ve Trend	No Trend	weak- ve Trend	- ve Trend
Oct 2018	Weak - ve Trend	+ ve Trend	Weak + ve Trend	Weak - ve Trend	- ve Trend	weak - ve Trend	- ve Trend
Nov 2018	Weak - ve Trend	Weak + ve Trend	Weak - ve Trend	Weak - ve Trend	weak - ve Trend	- ve Trend	- ve Trend
Dec 2018	Weak + ve Trend	Weak - ve Trend	Weak - ve Trend	Weak + ve Trend	- ve Trend	Weak + ve Trend	- ve Trend
Jan 2019	No Trend	Weak + ve Trend	- ve Trend	Weak - ve Trend	Weak - ve Trend	weak + ve Trend	- ve Trend

The above outcomes showing some kind of trend and in detail the reliability is showing positive trend and the availability is showing the negative trend. Hence it can be considered as the Non homogeneous poison process.[8,9,10] Hence the Power law process used for further analysis to find out the reliability and availability. The failure intensity function depends upon the cumulative time 't' (not the local time between failures).

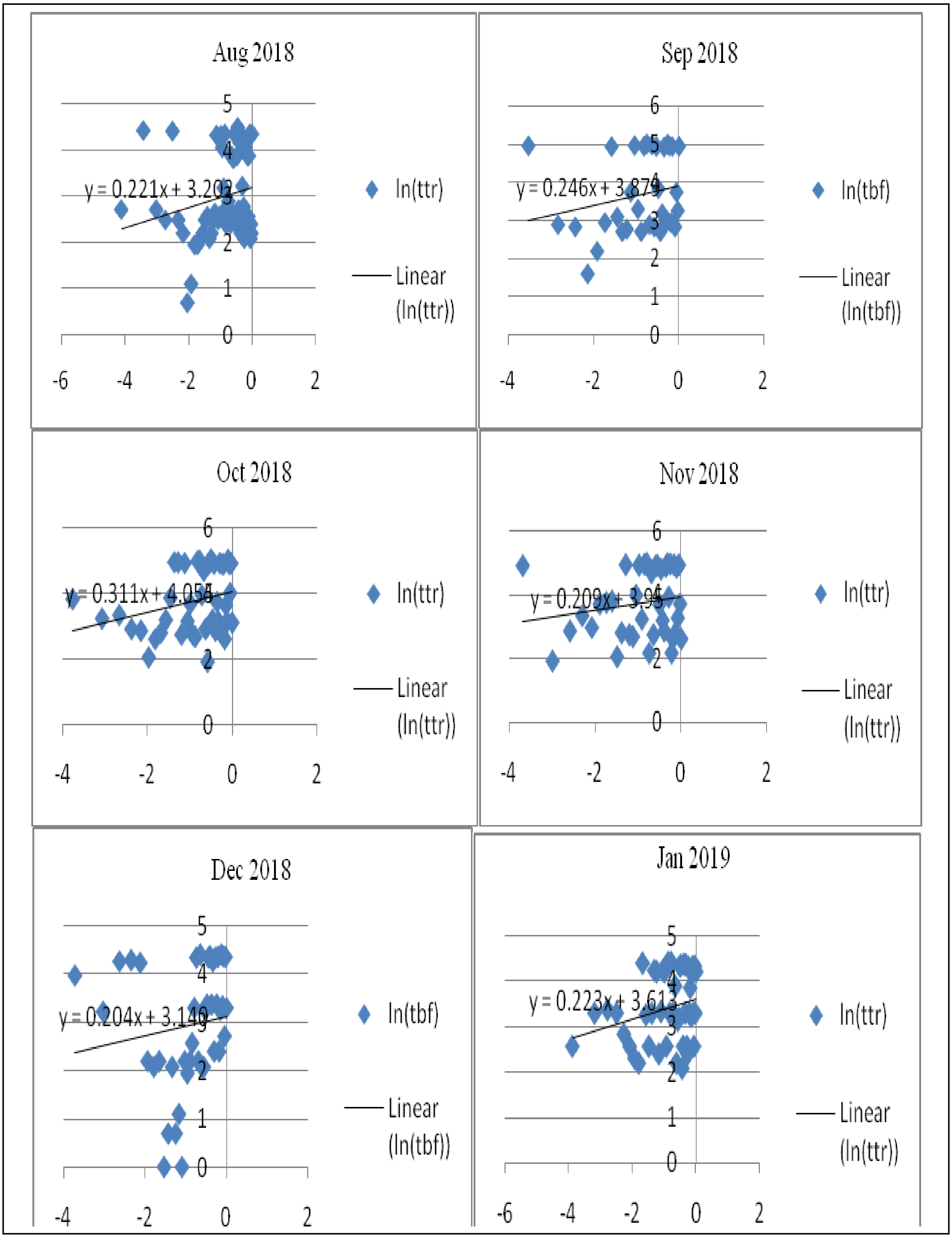

Figure 2: Graphs showing power law process for six consecutive months

Therefore the intensity function of Power law Process (NHPP) is given by

$$U_{(t)} = (\beta/\alpha)(t/\alpha)^{\beta-1} \qquad t>1$$

When α and β are scale and shape parameters and 't' is the global running time.[3,4] β indicates the nature of failure if it is positive the intensity function increases and if the value of β negative then the intensity function decreases. If β=0 then intensity function is constant.

III CALCULATIONS

RELIABILITY CALCULATIONS

$\alpha = \log t - \{ \log(MCRF) / \beta\}$; $R(t)= Exp(- (t/\alpha))^{\beta}$, $MCRF = (t/\alpha)^{\beta}$

TBF Based

Table II: Reliability calculations based on Time between failures

Parameter	Aug 2018	Sep 201	Oct 2018	Nov 2018	Dec 2018	Jan 2019
t	0.510	0.522	0.497	0.528	0.539	0.572
Log t	-0.2924	-0.2823	-0.3036	-0.297	0.2684	-0.2426
β	0.221	0.246	0.311	0.209	0.204	0.223
α	12	13.2	12.9	13.5	12.78	13.33
Log(MCRF)	0.5317	0.4459	0.3633	0.5079	0.5242	0.4955
R(t)	0.6080	0.6440	0.6954	0.6017	0.5920	0.6092

AVAILABILITY CALCULATIONS

$\alpha = \log t - \{ \log(MCRF) / \beta\}$; $A(t)= Exp(- (t/\alpha))^{\beta}$, $MCRF = (t/\alpha)^{\beta}$

TBF Based

Table III: Availability calculations based on Time to repairs

Parameter	Aug 2018	Sep 2018	Oct 2018	Nov 2018	Dec 2018	Jan 2019
t	0.576	0.610	0.541	0.567	0.588	0.549
Log t	-0.2395	-0.2146	-0.2668	-0.2464	-0.2306	-0.2604
β	0.217	0.226	0.231	0.297	0.268	0.273
α	12.5	12.78	13.01	12.68	13.29	13.16
Log(MCRF)	0.5128	0.5028	0.4797	0.3973	0.4335	0.4200
A(t)	0.5988	0.6048	0.6189	0.6721	0.6482	0.6570

IV OPTIMIZATION

WORK PIECE: The work piece here used is austenitic stainless steel alloy 304L of length 15cm length and 10cm width and various thickness. During the operation of welding the key parameters such as heat dissipated, rate of material removal rate, time of operation that is weld time and speed *and angle of operation. The above said parameters alter paradoxically with respect to* time.[5,6,7] With the observation all the parameters defined above are time dependant. Out of all the above said parameters the decision parameters in other words the decision variables must be found and in addition to that their dependency on other parameters and boundary conditions such as constraints has to be defined. The energy conserved during the operation is formulated as

$$\rho C_p\left\{\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial t} + (v - vo)\frac{\partial T}{\partial t} + w\frac{\partial T}{\partial t}\right\} = \frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right) + Qh + Qv \text{----------(1)}$$

Out of the above formulated equation the specific heart and density and thermal conductivity of the material being constant hence they can be ignored without much effect. U is the velocity term that is going to be altered hence its a parameter of importance. Q_h and Q_v are the terms of latent heat and adaptive heat source respectively. And the force exerted during the welding process is derived as below in the three directions out of them in y direction the welding is carried out.

$$F_x=\{(\mu_o I^2)/(4\pi^2\sigma_j^2 r)\}\exp(-r^2/(2\sigma_j^2))\{1- \exp(-r^2/(2\sigma_j^2))\}\left(1-\frac{z}{L}\right)^2 \frac{x}{r} \text{----------------------(2)}$$

$$F_y=\{(\mu_o I^2)/(4\pi^2\sigma_j^2 r)\}\exp(-r^2/(2\sigma_j^2))\{1- \exp(-r^2/(2\sigma_j^2))\}\left(1-\frac{z}{L}\right)^2 \frac{y}{r} \text{----------------------(3)}$$

$$F_z=\{(\mu_o I^2)/(4\pi^2\sigma_j^2 r)\}\exp(-r^2/(2\sigma_j^2))\{1- \exp(-r^2/(2\sigma_j^2))\}\left(1-\frac{z}{L}\right)^2 \frac{z}{r} \text{----------------------(4)}$$

The plasma arc force is derived as

$$P_a(x,y) = \{(\mu_o I^2)/(4\pi^2)\}\{(r_2^{-2}- r_1^{-2})+C_j*0.5*\sigma_j^2\exp(-3x^2/a_1^2-3y^2/b^2)\} \text{------------------------------(5)}$$

This is been utilized for the condition velocity of weld greater than molten metal in weld area. Based on this the objective function can be defined as

$$Z=213(r_2^{-2}- r_1^{-2})+21.978\exp(-3x^2/a_1^2-3y^2/b^2) \text{---(6)}$$

$Z_{min}=213(r_2^{-2}- r_1^{-2})+21.978 \exp(-341.2x^2-312.4y^2)$ --------------------------------------(7)

$g_1= 3r_2-2r_1\geq 0$--------------------------------------(8)

$g_2 = x-2y\leq 4$--------------------- -----------------(9)

Kuhn tucker equations are given by $(\partial f/\partial x)+\lambda_1((\partial g_1/\partial x)) +\lambda_2((\partial g_2/\partial x))=0$-------------------(10)

$(\partial f/\partial y)+\lambda_1((\partial g_1/\partial y)) +\lambda_2((\partial g_2/\partial y))=0$-------------------(11)

$(\partial f/\partial r_2)+\lambda_1((\partial g_1/\partial r_2)) +\lambda_2((\partial g_2/\partial r_2))=0$-------------------(12)

$(\partial f/\partial r_1)+\lambda_1((\partial g_1/\partial r_1)) +\lambda_2((\partial g_2/\partial r_1))=0$-------------------(13)

After solving the above equations the optimized values obtained as follows.

r_2=3.17mm, r_1= 4.532mm and x, y values are 1.79, 1.023.

V RESULTS AND DISCUSSION:

The plasma arc welding machine reliability and availability were calculated over a period of time and then it is found that the reliability is in the moderate limits and the availability is in co ordination with the reliability and finally it is evident that the machine performance is increasing and in addition to it the availability of the machine follows the same. Hence it is concluded that the machine is in its first phase of its life cycle from the bath tub curve. The below graphs shows the comparison of the reliability and availability of the machine with time.

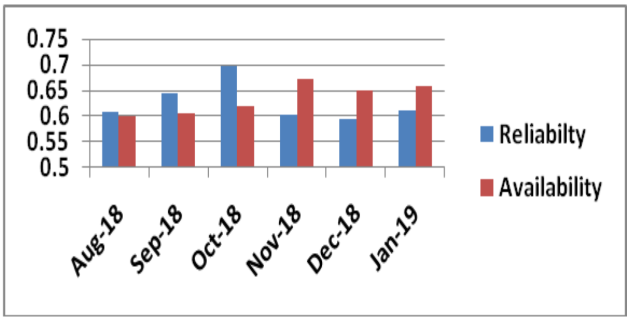

Figure 3: Comparison of Reliability and Availability for the six consecutive months

In addition to the above verdicts in a microscopic observation it is observed that in the first half if the experiment the reliability is dominant to the availability and in the second half the availability is dominant to the reliability. But as a overall availability is increasing and the reliability is slightly varying it is because of fatigue and stress. More research is to be carried out in this area for the further development and efficient operation.

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