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Analyzing the Geometrical Parameters of Ti 6Al 4V Welded Joint Subjected to Fatigue Load Using RSM Technique

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ABSTRACT: Weld joints of Titanium alloys are used widely in fatigue loaded applications. The failures of welded joints are in the appearance of crack propagation due to fatigue load. The Main objective of present work is to identify the fatigue strength, fatigue life of welded joints of Ti alloy (grade 5). The welded plates are joined in the cruciform shape using Tungsten Inert Gas weld and ERTi-5 as filler material. The specimens are tested on Instron servo hydraulic fatigue testing machine under constant load ratio(R=0) and frequency of 10Hz. Fatigue life of welded joints is influenced by the geometrical parameters like weld size, weld shape, plate thickness, weld penetration and fillet angle. Using RSM and ANOVA optimum values of geometrical parameters and their significance can be determined to obtain better fatigue life and fatigue strength. FEA analysis is done to predict the failure of joints for different weld shape

KEYWORDS:-Response surface Methodology, fatigue life, Design Matrix, Anova technique

Nomenclature:

RSM-Response surface Methodology

ANOVA-Analysis of Variance

DoE-Design of Experiments

CCD-Central composite Design

TIG- Tungsten Inert Gas Welding

CC-concave,CV-Convex,S1-Scalene triangle 1

FEA-Finite Element Analysis

SIF range-Stress Intensity Factor range(ΔK)

$\Delta\sigma$ =Applied Nominal stress

SEM-Scanning Electron Microscope

S2-Scalene triangle 2,

LOP-Lack of penetration

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I. INTRODUCTION

The increase in use of titanium alloy in various applications such as Aerospace, naval, chemical and biomedical engineering [1]. The tensile strength of titanium alloy can reach 1050 MPa based on heat treatment and chemical composition present today. It became necessary to investigate the applications of titanium alloy welded joint subjected to fatigue load. This Research aims to identify the geometrical parameters of cruciform welded joint of grade 5 of various weld shapes under fatigue loads. Experimental tests are conducted in order to find out the optimum geometrical parameters with help of Response surface methodology to obtain the optimum response which is known as fatigue life.

In this paper the role of Fractographs on Mechanical and fatigue properties of Ti 6Al 4V grade 5 welded plates were studied by analyzing the microstructure of welded plate and fatigue loaded welded plates are visualized with help of scanning electron microscope. FEA analysis is done to predict the failure of joints for different weld shapes.

In this investigation an attempt has been made to develop mathematical models to predict fatigue properties of pulsed current TIG welded titanium grade 5 weld joints. By means of the mathematical models, the geometrical parameters and strength of the weld joints can be predicted with 90% confidence level.

II. RELATED WORK

M. Balasubramanian et al [2] made an attempt to develop mathematical models to forecast tensile properties of GTA welded titanium alloy weldments by using RSM and ANOVA Technique.

Ramanjaneyulu.K et al [3] developed Regression equations based on the experimental values of maximum tensile strength and percentage elongation of the friction stir welded joints of aluminum alloy. He observed that developed models can be used to expect the responses within $\pm 10\%$ of their experimental values at 95% confidence level.

Olabi et al [4] studied RSM to examine the effect of laser welding parameters on residual stress distribution at various locations from the weld centre line of AISI304 butt joints.

Kundan et al [5] studied that TIG welding is one of the best material joining processes extensively used in industry. In his investigation he had made an attempt to develop the relationship to forecast the fatigue life by means of statistical tools such as DoE, ANOVA and regression analysis using Mini Tab Software 17.

In cruciform joints, usually identified defect is LOP, which is occurred at the joint because lack of access to the root region during process of fabrication. The structures of this welded joints present are frequently subjected to a fatigue type of loading. This might result in the beginning of a fatigue crack at the LOP defect, and the propagating of these cracks in the weld metal will result in the failure of the joint [6]. The LOP defect will influence the fatigue behavior of a fillet weld when its size increases; fatigue life is reduced significantly, this happens when the size of LOP is equal to half of the plate thickness. The failure of joint cannot be prevented apart from the required weld sizes by analyzing appropriately [8].

III. EXPERIMENTAL STUDIES

Specimen Details

Titanium alloy can be classified as either α alloy, β alloy or α - β alloys. The properties of α - β alloys (Ti grade 5) can be controlled through heat treatment [1]. Here aluminium is known as α -stabilizing element. Welding of titanium alloy is more difficult because at high temperature it is chemically resistant. The most commonly used welding method of titanium is TIG welding which significantly affects the mechanical properties of different zones of welded area.

Ti-6Al 4V plate (Grade 5) used as specimen. The dimension of one main plate and two cross plates 100 mm long \times 24 mm width and thickness of 8 mm. Tungsten inert gas Arc welding is done to join the plates in cruciform shape by using ER Ti5 filler rod material with help of TIG welding machine.

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Table 1:- TIG Welding Parameters

Welding current	60-65 amp
Filler material type	ER Ti-5
Shielding gas	Argon
Heat input	1.20 k.J/mm
travel speed	62 mm/min
Voltage	10-12 volts
Filler material dia	1.5 -2 mm
Type of shielding Gas	Argon
Shielding gas flow	8 -6 lit /min
Electrode	Tungsten

The base metal used in present experiment work is titanium alloy grade 5. The composition of the base metal in weight percent and mechanical properties are given in Tables 2 and 3 respectively.

Table 2:- Mechanical Properties of a material

Mechanical Properteis			
Ti Gr 5	UTS(Mpa)	YTS	% EI
ASTM B265	1050 Mpa	890	14

Table 3:-Chemical composition of work material

Ti 6al 4v grade 5 chemical composition in weight percent							
Ti Gr5	C	Al	V	Fe	H	N	O
	0.08	5.8	4.0	0.3	0.015	0.03	0.23

Fabrication of specimens

In present work Ti-6Al 4V plate (Grade 5) used as specimen and its chemical & mechanical properties are shown in table 2 &3. The dimension of the main plate and two cross plates are 100 mm long × 24 mm width and thickness of 6 mm. Tungsten inert gas arc welding is done to join the plates in cruciform shape by using ER Ti5 filler rod material with help of TIG welding machine. Titanium gr-5 plates are rarely available



Fig 1: Welding of Ti-6Al-4V plates

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Fatigue test.

Cruciform shape welded are placed in the grippers and experiments were conducted with constant ratio (R=0) and exciting load is applied on the cross plate of specimen with frequency of 10Hz. By applying the stress range on specimen and to attain failure of joint at welded part was recorded in the form of number of cycles which is observed in table 5 as a output response.



Fig 2: Fatigue testing Machine



Fig 3 : Specimen placed in Fatigue testing Machine

X_i in the equation is the resulting coded value of a variable X, here X indicates a value of the variable between X_{max} to X_{min} , and X_{min} is the inferior and X_{max} is the greater limit of the variable. The control parameters with levels are shown in Table 4. Total of 16 experiments, 2levels with four factors were performed, to obtain output response as fatigue life as shown in Table 5

$$X_i = [2 X - (X_{max} + X_{min})] / (X_{max} - X_{min}) / 2 \dots\dots (1)$$

Table 4:- Geometrical Parameters and its levels

Control Parameters	Symbol	Levels	
		Low(-1)	High(+1)
Initial LOP/filler width (a/w)	C	0.2	0.6
Leg length/plate thickness(L/Tp)	P	0.6	1
Fillet angle	f	30 degrees	60 degrees
Nominal stress	S	220 Mpa	320 Mpa

The sixteen experiments has been formulate in the form of as per 2^4 factorial design (two levels and four factors) and in support of major effects with the formula 2^{nc-1} for the low (-1) and high (+1) values. Where n_c refers to Number of columns.

By applying different stress ranges on the material the number of cycles are recorded.16 Experimental tests were done to arrive the design matrix. In design matrix the geometric control parameters and its levels are given in table 4

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IV. DESIGN OF EXPERIMENTS AND RESPONSE SURFACE METHODOLOGY

By observing above conditions, the levels of the parameters are chosen in such a manner that the grade 5 alloy is to be welded with no any weld defects. For the ease of recording and giving out the experimental data, the superior and inferior levels of the control factors are has been indicated as +1 and -1 and these coded values of every intermediate levels can be calculate by using the expression X_i .

RSM is a set of exact and geometric techniques helpful for analyzing the problems in which numerous nondependent variables which the influence a response. Main aim of the RSM is to find those settings of process parameters that give most favorable value of the response. RSM provides a regression form that establishes relationship among the control parameters and response. This relationship can be used to predict the response when the process parameters are varied within the chosen ranges.

Table:-5 Experimental layout using CCD with Fatigue life data

Expt No	Specimen ID	Geometrical Parameters				Fatigue life is $N \times 10^5$
		Initial LOP/ fillet width	Leg length/plate thickness	Fillet angle	Nominal stress (S)	
		(C)	(P)	(f)		
1	CC1	-1	-1	-1	-1	3.16
2	CC4	1	-1	-1	-1	1.65
3	CC9	-1	1	-1	-1	2.25
4	CC10	1	1	-1	-1	4.19
5	FT2	-1	-1	1	-1	3.27
6	FT5	1	-1	1	-1	2.89
7	FT7	-1	1	1	-1	4.68
8	FT8	1	1	1	-1	2.43
9	CV2	-1	-1	-1	1	0.21
10	CV5	1	-1	-1	1	0.68
11	CV6	-1	1	-1	1	2.16
12	CV9	1	1	-1	1	0.90
13	FT4	-1	-1	1	1	0.22
14	FT5	1	-1	1	1	0.34
15	CC2	-1	1	1	1	0.62
16	CV3	1	1	1	1	0.75

Fatigue life is function of four factors thus the linear polynomial regression equation can be expressed as

$$Y = \alpha_0 + \sum \alpha_i x_i + \sum \alpha_{ij} x_i x_j + \epsilon_0$$

$$Y = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 + \alpha_3 x_3 + \alpha_4 x_4 + \alpha_{12} x_1 x_2 + \alpha_{13} x_1 x_3 + \alpha_{14} x_1 x_4 + \alpha_{23} x_2 x_3 + \alpha_{24} x_2 x_4 + \alpha_{34} x_3 x_4 \dots \dots \dots (2)$$

Developing Mathematical Model

CCD's are well known as response surface designs which can fit a complete quadratic form [6]. For our convenience, assume each factor varies from -1 to +1.

To find out the approximate regression coefficients, few number of investigational design methods are presented. In present work, CCD is used which fits in the second order response surface precisely. Coefficients of all parameters will be obtained by applying CCD by using the Mini tab software. By determining the major coefficient, the final correlation was developed by means of only these coefficients.

The relationship to expect the fatigue life of TIG weld joints of grade 5 is specified by following equation

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Fatigue life = $(2.1075 - 0.3788 C + 0.5550 P - 0.2075 f - 1.3725 - 0.2163 CP + 0.0812 CP + 0.3113 CS - 0.3350 Pf - 0.1825 PS - 0.0450f S) \times 10^5 \dots(3)$

The coefficient of (R^2) is used to come across the closeness of experimental and predicted values which is calculated by means of the following expression

$$R^2 = \frac{\sum (Y_p - Y_a)^2}{\sum (Y_e - Y_a)^2} \dots(4)$$

Y_p is the predicted weld strength Y_e is the investigational weld strength; and Y_a is the mean of experimental values.

V. ANOVA TECHNIQUE

The developed model is tested by means of the ANOVA technique and the output of second order response surface model appropriate is given in Table 6. The determination coefficient (R^2) indicates the righteousness of fit to the model. In present case, the value of the determination coefficient ($R^2=0.86$) and value of adjusted determination coefficient (adjusted $R^2=0.811$) is low but is closer to the R^2 value, which indicates a significance of the model. The value of possibility is greater than F value as shown in Table 6 for model the value should be less than 0.05, which resembles that the model is best significant.

The assessment of " R^2 " for the developed relationship is as well represented in Table 6 and this indicates maximum correlation is occurred among the experimental as well as predicted values.

Pred R^2 of 0.8615 is in sensible conformity by means of the Adj R^2 of 0.8712. "Adeq Precision" will trial the S/N ratio. Above consideration indicates a sufficiency of the developed empirical relationship. The normal probability plot for residuals of fatigue life is shown in Fig 8, which finds that the residuals are very near to the reference straight line, and that indicates the errors distribution is normal to fatigue life.

Table - 6:- ANOVA for Fatigue Life using Adj Sum of Squares for Test

Source	Dof	Seq SS	Adj SS	Adj MS	F	P	
C	1	2.295	2.295	2.295	4.13	0.057	significa nt
P	1	4.928	4.928	4.928	8.86	0.013	significa nt
f	1	0.6889	0.688	0.688	1.24	0.289	
S	1	30.1401	30.140	30.14	54.2	0.367	
C*P	1	0.205	0.205	0.205	2.46	0.025	significa nt
C*S	1	0.070	0.070	0.070	0.84	0.75	
P*f	1	0.890	0.890	0.890	10.68	0.043	significa nt
P*S	1	1.257	1.257	1.257	15.84	1.05	
f*S	1	0.369	0.369	0.369	4.428	0.13	
Error	11	6.1169	6.1169	0.556			
Total	15	44.1695					
S= 0.745707		R-Sq = 86.15%		R-Sq(adj) = 87.12%			
PRESS = 12.9415		R-Sq(pred) = 85.70%					

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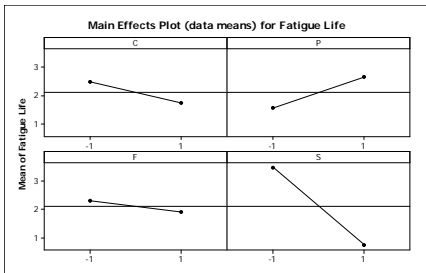


Fig 4: Main effect plot for Fatigue life

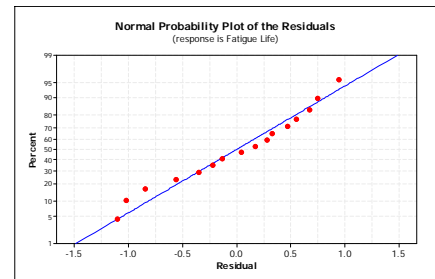


Fig 5:-Normal probability plot of residuals

From the Fig.4 the optimum values of geometrical parameters are $C = -1$ (low) $P = +1$ (high) $f = -1$ (low) $S = -1$ (high). Lower a/W ratio, Higher L/T_p ratio, less fillet angle and lower nominal stress value gives the optimum value for fatigue life is around 1.7×10^5 cycles.

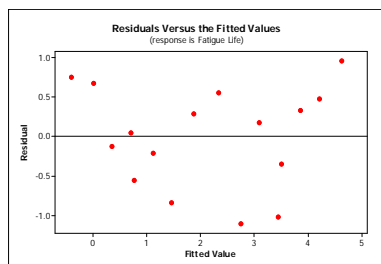


Fig 6:- Response vs. Fitted Values

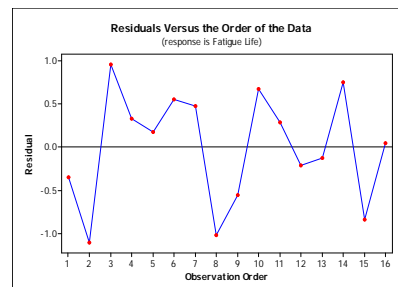


Fig 7:- Residuals vs. Observation order Plots

The plot of normal probability for residuals of fatigue life is represented in Fig.5 shows that residuals are located along the reference straight line, which shows the errors were scattered normally. This consideration indicates the sufficient value of the regression model.

From fig 6 it is identified that the steady variance assumption was verified with plot of residuals vs fits this plot represents to show a random pattern of residuals on either sides of 0 and it does not disclose any familiar patterns. Therefore a common pattern is considered that the when residuals values increase as the fitted values increase the fatigue life.

The observations should be randomly selected from the centre line and therefore assumption is violated therefore independent assumption is to be satisfied if the plot does not make known of any pattern as shown in fig 7

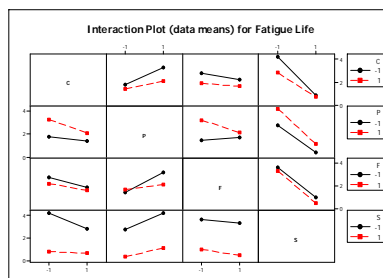


Fig 8:-Interaction plot

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The fatigue strength for each experimental run is investigated by using the interaction plot is shown in Figure 8 The interaction plot illustrates an interaction between all the levels and parameters for effective optimization From figure, it shows that the lines are not parallel to each other for all levels of factors.

It is considered that to obtain optimum fatigue strength the geometrical parameters for the Ti 6Al 4V joint are as follows $a/W = 0.2$, $L/TP = 1$, $f = 30^{\circ}-45^{\circ}$ and $S = 220$ Mpa. For above control parameters the experimental result for fatigue strength is 2.25×10^5 cycles.

VI. CONCLUSION

The geometrical parameters and the only some Interactions are found to be significant in determining the weld strength of the cruciform welded specimens. Empirical relationship is arrived to forecast the Number of cycles of load carrying TIG weld joints of Ti 6Al 4V grade 5

a) The developed relationship is successfully used to find out the fatigue life and geometrical properties of load carrying TIG welded cruciform joints failing from weld area at 87 % confidence level

b) The studies on cruciform welded joint proportions on fatigue life were analyzed in detail. Lower a/W ratio, Larger weld size (L/TP ratio), moderate fillet angle and nominal stress value gives better fatigue life when compared with other combinations.

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