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Effect of Process Parameters on Angular Distortion of Gas Tungsten Arc Welded SS 302 and MS Plate

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ABSTRACT: Tungsten Inert Gas (TIG) welding is a widely applied manufacturing process. Angular distortion is a major problem and most pronounced among different types of distortion in the butt welded plates. This angular distortion is mainly due to nonuniform transverse shrinkage along the depth of the plates welded. Restriction of this distortion by restraint may lead to higher residual stresses. However, these can be reduced by providing initial angular distortion in the negative direction if the magnitude of angular distortion is predictable. It is difficult to obtain a complete analytical solution to predict angular distortion that may be reliable over a wide range of processes, materials, and process control parameters. ANOVA is applied for the optimization of weld parameters control. In this study the transverse distortion of TIG, welding process was evaluated using weld current, filler rod diameter, length of plate and time gap between passes as the main parameters. A L9 orthogonal array was selected for the design of experiments towards the distortion optimization caused by butt welding. A mathematical model was developed correlating the process parameters with angular distortion. A source code was developed in MATLAB 16 to do the optimization. Direct and interaction effects of the process parameters were analyzed and presented in the graphical form. Further, these mathematical models help to optimize the GTAW process and to make it a cost-effective one by eliminating the weld defects due to angular distortion.

Keywords: TIG, Angular distortion, DOE, Mathematical Model, Regression method.

I. INTRODUCTION

Gas tungsten arc welding is an arc welding process that produces coalescence of metals by heating them with an arc between a non consumable electrode and base metal. It is suitable for joining thin and medium thickness materials like stainless steel and for applications where metallurgical control of the weld metal is critical . Stainless steel grade 202 has wide applications in making seamless stainless steel tube for boilers, heat exchangers tubes, super heater tubes, cook wares etc. In arc welding process, due to rapid heating and cooling, the work piece undergoes an uneven expansion and contraction in all directions. This leads to distortion in work piece. Angular distortion or out of plane of distortion is one such defect that makes the work piece distorted in angular directions around the weld interface. Post weld treatment is required to eliminate the distortion so that the work piece is defect free and accepted.

Vinokurov has discussed how angular distortion is directly influenced by the welding input parameters such as welding gun angle, welding current, nozzle to plate distance and welding speed during the welding process. One of the methods to remove the angular distortion during the fabrication process is to provide an initial angular distortion in the negative direction. If an exact magnitude of angular distortion is predicted, then a weld with no angular distortion will be the result. It is difficult to obtain analytical solution to predict angular distortion. Costly and time consuming experiments are required to determine the optimum welding process parameters using conventional optimization techniques. These conventional techniques require more computational effort and time.

TIG welding process

TIG welding is a process which uses the heat of electric arc between the non-consumable Tungsten electrode and work piece for melting of faying surfaces and inert gas is used for shielding the arc zone from atmospheric gases. TIG welding is widely used for welding of metals like stainless steel, some alloy grades of Aluminium, Mg materials. It is used in critical applications like for precision welding in nuclear structural materials fabrication, air craft, chemical, petroleum, automobile and space craft industries. The Tungsten arc process is being employed widely from the precision joining of critical components which require controlled heat input. The small intense heat provided by the Tungsten arc is ideally suited to the controlled melting of the thin sheets, sometimes without filler rods. Advantages of TIG welding are concentrated arc, no slag, no splatter, little smoke or fumes, good weld penetration, preferred for stainless steel alloys. Disadvantages are slow process, good skill requirement for manual operation.

Control of weld Distortion

If distortion is to be prevented or minimized in a weldment, strategies must be used in the design and in shop practices to overcome the effects of the heating and cooling cycles. Shrinkage or contraction cannot be prevented, but it can be controlled. Departure from initial dimensional specifications in a fabricated structure or component as a consequence of welding is called welding distortion. Welding involves highly localized heating of the metal being joined together to cause melting of base metal and rejoining with recrystallization of grain structure of base material. The temperature distribution in the weldment is therefore non uniform. Normally, the weld metal and the heat affected zone (HAZ) are at temperatures substantially above that of the unaffected base metal. Upon cooling, the weld pool solidifies and shrinks, exerting stresses on the surrounding weld metal and heat affected zone. Several types of distortion can occur in joining metals due to longitudinal shrinkage, transverse shrinkage, angular distortion, fillet distortion, neutral axis distortion. The pictorial representation as mentioned in Figure 1 shows that the shape of the components modify due to distortion in longitudinal, along the length of the weld and in the transverse, perpendicular to weld direction. Transverse distortion can be measured as the distortion angle measured from weld point as angular distortion.

In the present reported work, transverse distortion is measured and expressed in angular distortion in degrees. If a component were uniformly heated and cooled, distortion would be minimized. However, welding locally heats a component and the adjacent cold metal restrains the heated material. This generates stresses greater than yield stress causing permanent distortion of the component. Some of the factors that affect distortion are kind of restraint, amount of restraint, welding procedure, properties of parent metal etc. Because welding involves highly localized heating of joint edges to fuse the material, non-uniform stresses are set up in the component because of expansion and contraction of the heated material. As shown in Figure1, distortion causes change in shape and orthogonal reduction in length, shrinkage in both longitudinal and transverse direction. The front view of welded component shows the transverse distortion which is an angular movement of the part about the weld point.The smaller parts considered in this report result in a linear angular movement which is the response considered in this study. Initially, compressive stresses are created in the surrounding cold parent metal when the weld pool is formed due to the thermal expansion process of the hot metal (heat affected zone) adjacent to the weld pool. However, tensile stresses occur on cooling when the contraction of the weld metal and the immediate heat affected zone is resisted by the bulk of the cold parent metal. The magnitude of thermal stresses induced into the material can be seen by the volume change in the weld area on solidification and subsequent cooling to room temperature.

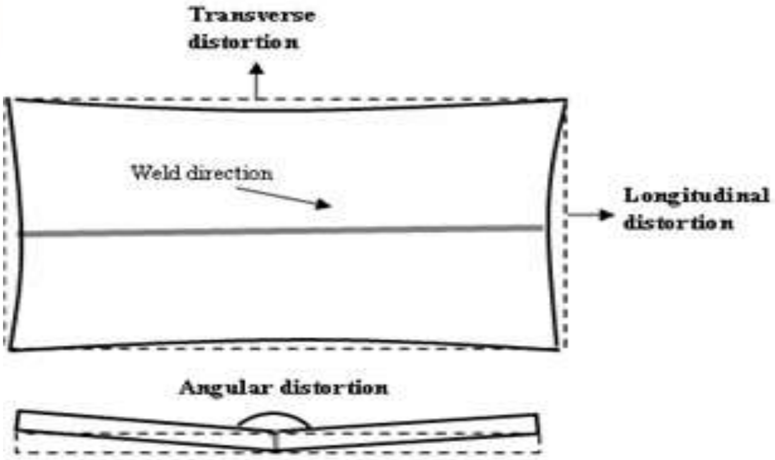


Fig. 1: Distortions caused by welding

II. MATERIAL AND METHODOLOGY

TIG welding was carried out with SS 302 & MS samples of varying length, 50 mm width and 6mm thick. The SS and MS plates were prepared with V grove design and butt weld conditions with single pass filler wire. The distortions are observed in all the samples and are measured with dial gauge fitted to a height gauge. Tungsten Electrode was connected to the Negative charge of the DC hence, Tungsten Electrode Negatively connected, called EN type welding. The current variation was 70 to 100 Amps.. The filler material used was a carbon steel filler rod of 1.5-2.5 mm diameter. The process was stabilized to minimize the variation due to uncontrolled parameters or manual error bias.

The Welding machine used was a Weld man EJM 300 TIG, an AC/DC, 3 Phase, 50 Hz, pulse controlled dual, TIG & Arc welding machine capable of welding 0.8 mm to 19 mm thick plates. The two plates placed with the root gap at the bottom and the angle provides a V groove for the weld bead. The weld bead will be the rectangular area of root gap and plate thickness, triangular bead area of V groove and the top bead chord area. The weld process parameters which are used as main factors are mentioned in Table 1 with details and rest other parameters are kept same throughout the experiments.

Table I: Major Process parameters for TIG welding.

Sr. No.	Process Parameters	Notation	Units	Levels		
				-1	0	1
1	Length of Work piece	l	mm	75	100	125
2	Diameter of Electrode	d	mm	1.5	2	2.5
3	Weld Current	c	amps	70	85	100
4	Time gap between passes	t	min.	0	5	10

Genichi Taguchi has used the design of experiments effectively to improve quality, productivity, reliability, and cost and is extensively used in industry as a tool in their TQM or Six Sigma activities. The use of Orthogonal Arrays, in this study, an L9 experiment, was done is a fractional factorial methodology. L9 has designed 9 unbiased experiments which have been conducted randomly, not in 1 to 9 sequences to remove the experimental bias. The control factors are allotted to the columns as shown in Table 2. Four factors, length of work piece, Weld current, electrode diameter and time gap between passes were allotted to the columns, 1, 2, 3 & 4 respectively. Each of these factors has three levels of possible values and they are assigned to form the orthogonal experimentation. The output distortion is expressed in degrees of distortion, an angular unit obtained from Trigonometry of the measured values.

Table II: L9 Orthogonal array experimental lay out

Trails	l	d	c	t	dis
1	75	1.5	70	0	6.16
2	75	2	85	5	4.30
3	75	2.5	100	10	6.73
4	100	1.5	85	10	5.80
5	100	2	100	0	4.80
6	100	2.5	70	5	2.83
7	125	1.5	100	5	5.37
8	125	2	70	10	4.70
9	125	2.5	85	0	4.35

Model was developed by the method of regression. Adequacy of the model and significance of coefficients was tested by the analysis of variance technique and regression method respectively. By finding the regression coefficients we get the mathematical model.

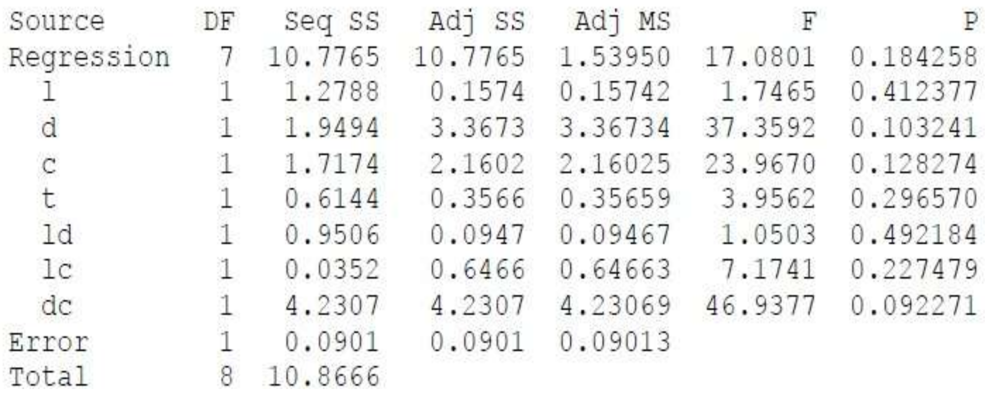
$$D_2 = b_0 + b_1 l + b_2 d + b_3 c + b_4 t + b_{12} ld + b_{13} lc + b_{14} lt + b_{23} dc + b_{24} dt + b_{34} ct$$

Regression Equation (using MINITAB 16):

Distortion (D_2) = 61.2644 - 0.154571 l - 18.4462 d - 0.766333 c +0.129 t - 0.0322286 ld + 0.00280762 lc + 0.253905 dc

Validity of the developed models was tested by drawing scatter diagrams that show the observed and predicted values of angular distortion. A representative scatter diagram is shown in Fig. 3. To determine accuracy of the model conformity, test runs were conducted. For these runs, process parameters were assigned some intermediate values within their limits. A comparison was made between actual and predicted values. The result shows that the model accuracy is above 95%.

Table III: Analysis of variance



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Source      DF   Seq SS   Adj SS    Adj MS        F         P
Regression   7  10.7765  10.7765   1.53950  17.0801  0.184258
  l          1   1.2788   0.1574   0.15742   1.7465  0.412377
  d          1   1.9494   3.3673   3.36734  37.3592  0.103241
  c          1   1.7174   2.1602   2.16025  23.9670  0.128274
  t          1   0.6144   0.3566   0.35659   3.9562  0.296570
  ld         1   0.9506   0.0947   0.09467   1.0503  0.492184
  lc         1   0.0352   0.6466   0.64663   7.1741  0.227479
  dc         1   4.2307   4.2307   4.23069  46.9377  0.092271
Error        1   0.0901   0.0901   0.09013
Total        8  10.8666
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Where,
DF - degrees of freedom,
SS - sum of squares,
MS - mean squares (Variance),
F-ratio of variance of a source to variance of error,

Table IV: values of distortion observed (from experiment) and calculated (mathematical model)

D_1	D_2	% error
Observed values of Angular distortion	Calculated values of Angular distortion	
6.16	6.133278	0.434
4.30	4.514007	4.977
6.73	6.703313	0.396
5.80	5.693063	1.844
4.80	4.693080	2.227
2.83	2.723055	3.779
5.37	5.423563	0.997
4.70	4.753540	1.139
4.35	4.403558	1.231

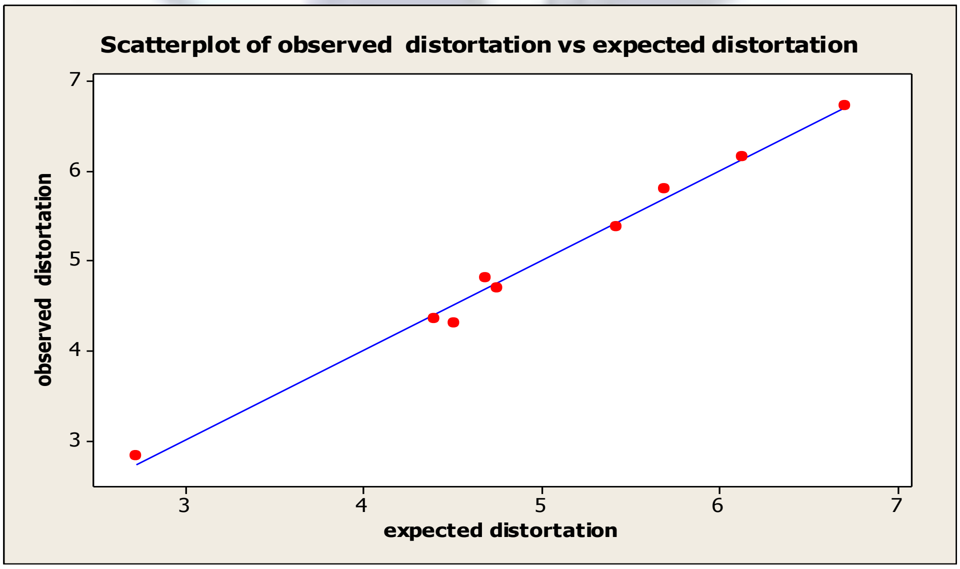

Fig. 2: plot between observed and calculated values of distortion.

III. RESULTS AND PLOTS

The mathematical model given above can be used to predict the angular distortion by substituting the values of the respective process parameters. Also, the values of the process parameters can be obtained by substituting the value of allowable angular distortion values. The angular distortions calculated from the final model for each set of coded values of welding parameters are represented graphically in Figs 3-8. These graphs show generally convincing trends between cause and effect.

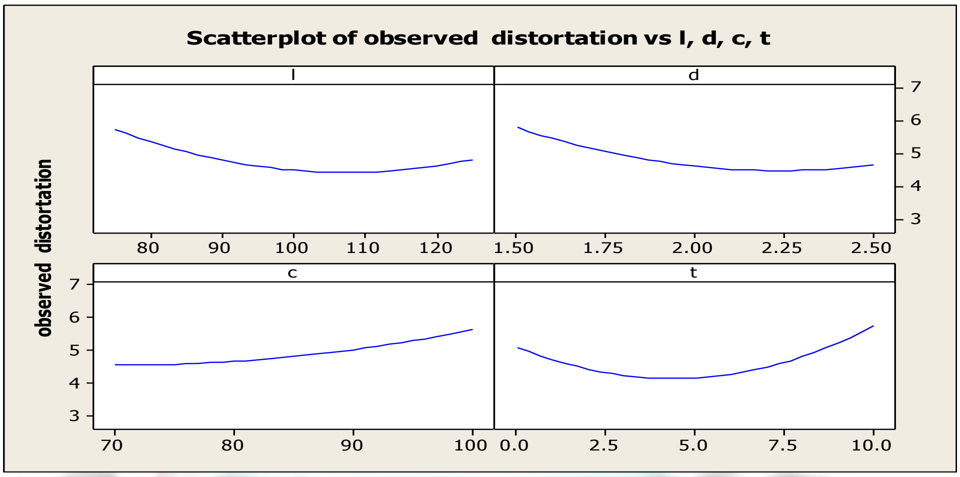

Fig. 3: Scatter plot of angular distortion vs factors.

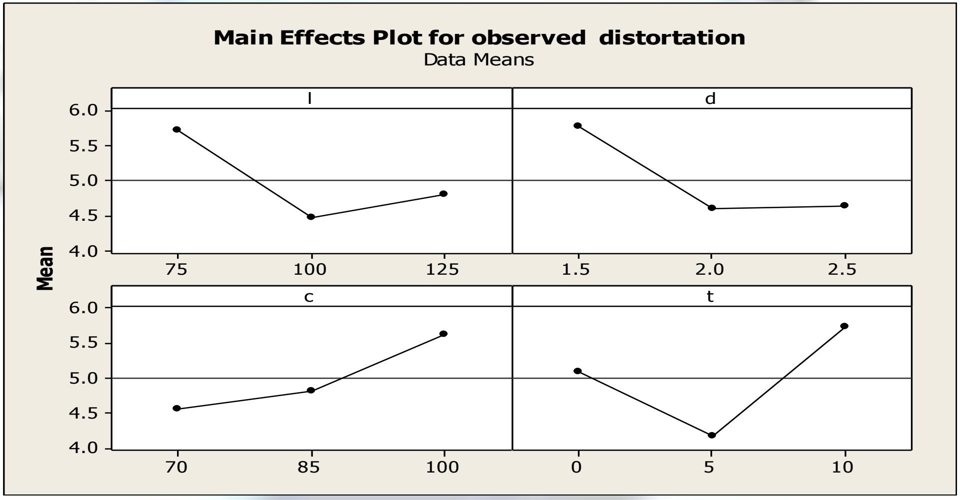

Fig. 4: Mean effects plot for angular distortion.

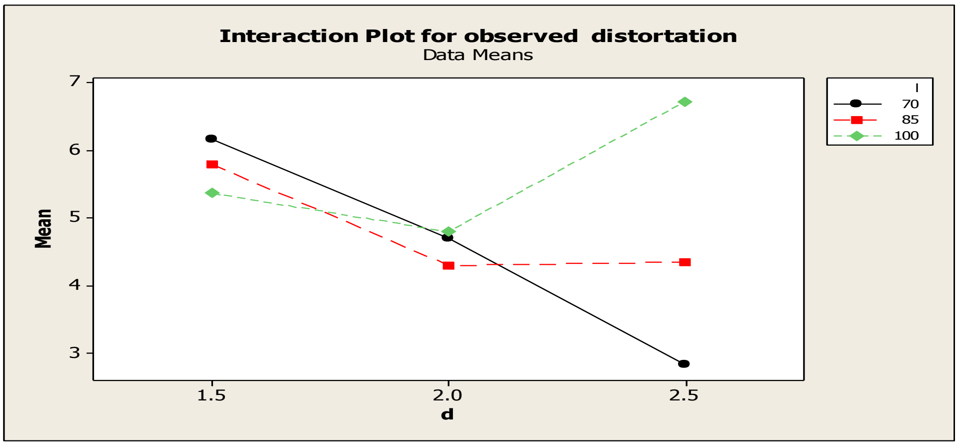

Fig. 5: Interaction effect of length of plates and diameter of electrode on Angular distortion.

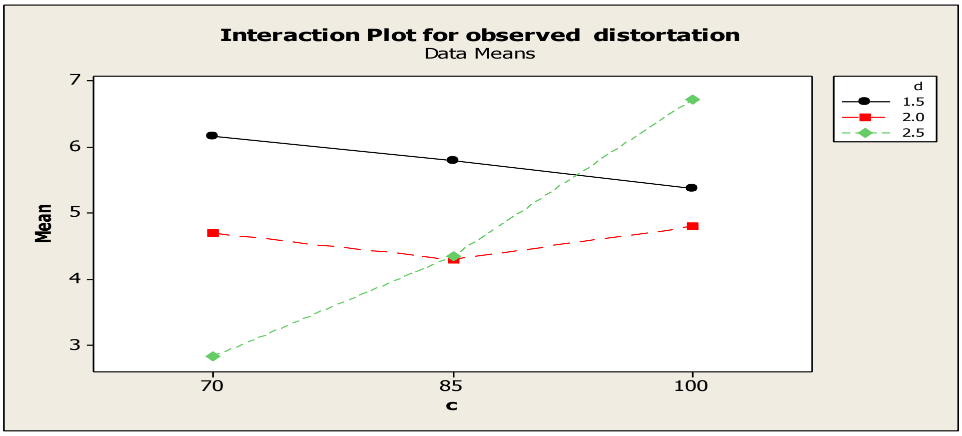

Fig. 6: Interaction effect of diameter of electrode and current on angular distortion.

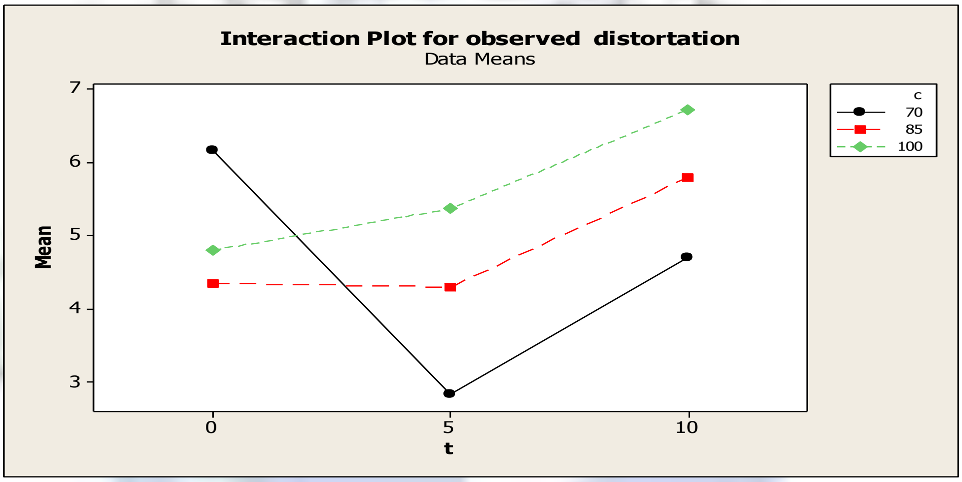

Fig. 7: Interaction effect of current and time between passes on Angular distortion.

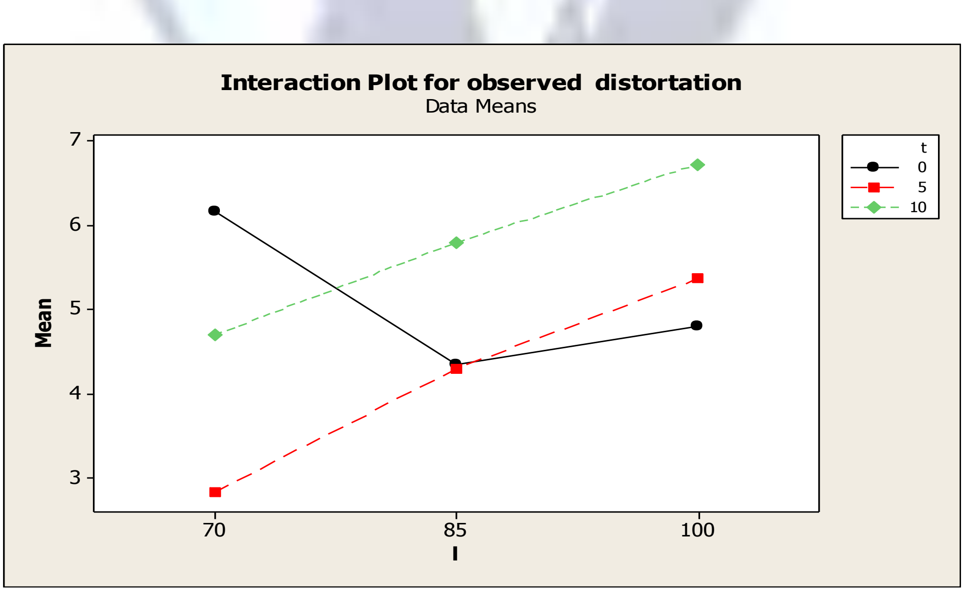

Fig. 8: Interaction effect of time between passes and length of plates on Angular distortion.

CONCLUSION

The following conclusions were arrived at from the above investigation:

Angular distortion has positive effect with increase in length of plates and diameter of electrode. Angular distortion has negative effect with increase in current and time gap between passes. Within the design range of parameters, the highest effect on angular distortion is found of diameter of the electrode. Within the design range of parameters, the least effect on angular distortion is found of time between successive passes.

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