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EMPHASIS OF PLATE-THICKNESS AND GROOVE ANGLE ON DISTORTION FOR MILD STEEL BUTT JOINTS

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Abstract - *Welding is a process of joining two or more similar/dissimilar material with/without application of heat with/without the use of filler material and pressure. There are several welding defects occurs during and post welding due to weldments to variation in heat application and poor design that results fail of weldments under service conditions as cracking, porosity, poor fit-up, and distortion. In the current research, attention has been paid to minimize one of the significant welding defect termed 'Distortion.' Distortion is the change in shape and variation between the positions of the two plates before welding and after welding. Medium carbon steel (mild steel) has been preferred as parent metal, with variable plate-thickness (6,7 and 8mm) and groove angle(60, 90, 120) as input variables with the application of MMAW technique. Direct and interactive effects of plate thickness and groove angle of MS had been explained over distortion, and predictive mathematical model had been developed for quantification of distortion. The results are verified by the analysis of variance (ANOVA) technique using Design-Expert software.*

Key Words: **Distortion, Mild Steel, Butt Joint, Arc Welding, Single V Groove, ANOVA**

1 INTRODUCTION

Manual metal arc welding (MMAW) has widespread applications in ship buildings, constructions, aerospace, automobile industries, etc. due to its application-easiness of, low cost and use of portable-equipments[1]. To assure the specific characteristics of the weldment, however, it is necessary to apprehend, how the welding parameters influence the process's outcome [2]. Weld should be defect free and deposited with the desired geometry, with efficiency, and with minimal waste of material. Distortion occurs due to the variation in temperature difference at different points along the joint, and that results in local expansion of base metal and o weld bead contraction [3]. Distortion is the result of pure ignorance that is approaching the job holding. The most critical factors in the production of a successful and economical weldment or broken part repair are the minimization of distortion. Excessive distortion increases the operational cost due to the expense of rectification or may cause job carelessly [4]. The degree of angular distortion varies with plate-thickness, joint-type, number of passes, thermo-mechanical properties of the parent metal, the process variables [4]. Thus welding deformation not only complicates the fabrication of welded structure but also minimize its fitness for the job for which it is designed. Moreover in welding causes locked up stress or residual stress in the weld zone which on the one hand contributes to weld cracking and on the other size it is suspected to have a significant effect on the brittle fracture of the welded structures. This may also reduce the load carrying capacity of the member [5].

Kihara, et al. had investigated the effect of process variables on the angular distortion for butt-welds [6]. Hirai, et al. had conducted research to understand variation in angular distortion as a variable of plate-thickness and electrode-quantity [7]. Mandal, et al. applied a statistical technique for 2-level factorial method and summarized that welding-speed had a positive influence on angular distortion [8].

Literature review report that detailed studies of distortion had been carried out by so numerous authors, still there is general lack of empirical data on different types of distortion such as transverse and longitudinal, shrinkage, angular distortion, bowing particularly for butt weld (v-groove) joint. Few researchers had provided detail analysis of angular distortion still groove angle and plate thickness is barely considered. Moreover, the availability of data on other types of distortion is so scared that the verification of theoretical prediction is difficult.

In present empirical practice, mathematical-model was crafted to establish a relationship between groove-angle (A) and plate-thickness (B) for angular-distortion in mild steel welded plates using MMAW technique. To prediction distortion, its comprehensive analysis is conducted for developing a mathematical model with the application of response surface methodology and results are verified using ANOVA technique.

2. EXPERIMENTAL WORK

Experimental work was designed for measuring the longitudinal shrinkage and transverse shrinkage distortion of butt weld joints having distinctive groove angle and different thickness for the mild steel plates with application of ER-4211 filler wire (Make: Manglam, size: 3.15mm x 450mm) using manual metal arc welding machine (Make: Crown, current range: 50A to 110A, voltage: 40V).

Fig 1.(a).M.S. plates prior to cleaning

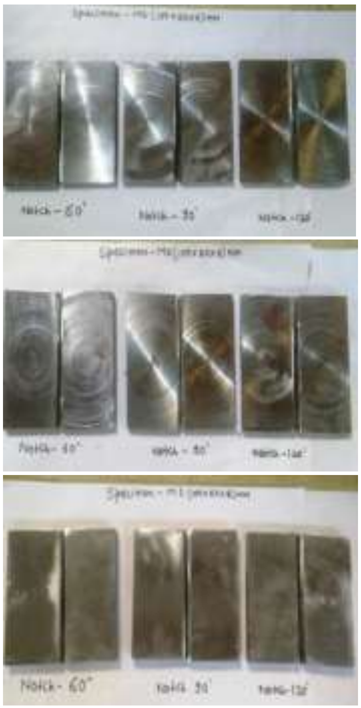

Fig 1.(a).M.S. plates after mechanical and chemical cleaning and weld groove preparation

Fig. 1. Mild steel plates before welding

2.1 Weld- plate preparation

Eighteen numbers of variable thickness (6 mm, 7 mm & 8 mm)

Table-1 Development of design of experiment (DOE) in coded factors

Factor 1	Factor 2	Response 1	Response 2
A:A	B:B	Transverse shrinkage (Mild steel) in mm	Longitudinal shrinkage (mild steel) in mm
1	0	3.4987	1.17
0	-1	1.6884	0.734
-1	1	1.4285	1.68
-1	-1	1.4059	0.41
0	0	2.6469	1.074
1	-1	3.0486	0.891
-1	0	1.8397	0.96
1	1	2.2135	1.831
0	1	1.8965	1.672

mild steel test plates were cut by power hacksaw from a rolled Indian standard plate, ISP 16 of dimension 100 mm x 50 mm x 8 mm. V grooves are made on these plate as mentioned in the Figures 1. Manual metal arc welding is conducted after mechanical and chemical cleaning to remove any dust or foreign particles.

2.2 Recording of response

Shrinkage for butt welds could be calculated by Equations 1 and 2.

1. Transverse shrinkage of butt welds-

$$S = 5.16 \times (A_W / t) + 1.27\, d \quad (1)$$

Where,
S = transverse shrinkage,
A_w = cross-sectional area of weld
t = thickness of plates
d = root opening.
Longitudinal shrinkage of butt welds-

$$\Delta L / L = 3.17 \times I \times L / 100{,}000 \times t \quad (2)$$

Table 2- Transverse shrinkage in Mild steel plates (Uncoded).

S.No.	Plate thickness in mm.	Weld section in degree	Average transverse shrinkage in mm.
1	8	60^0	3.4987
2	7	60^0	1.6884
3	6	60^0	1.4285
4	8	90^0	1.4059
5	7	90^0	2.6469
6	6	90^0	3.0486
7	8	120^0	1.8397
8	7	120^0	2.2135
9	6	120^0	1.8965

Where,
ΔL = longitudinal shrinkage (mm.)
L = length of weld (mm.)
t = thickness of plate (mm.)
I = welding current (mm.)
The values obtained for longitudinal shrinkage are mentioned below in Table 3 for all the work-pieces (i.e. P1 to P9).

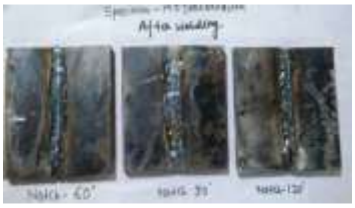

Fig. 2. Mild steel weld-specimens after welding

Table 3- Average longitudinal shrinkage in mild steel plates (Uncoded).

S.No.	Plate thickness in mm.	Weld section in degree	Average longitudinal shrinkage in mm
1	8	60^0	1.012
2	7	60^0	0.631
3	6	60^0	0.690
4	8	90^0	1.494
5	7	90^0	1.125
6	6	90^0	1.096
7	8	120^0	1.916
8	7	120^0	1.741
9	6	120^0	1.17

3. Development of mathematical model

Deflection and shrinkage for Mild steel plate could be represented as a function of two factors groove-angle (A) and plate-thickness (B), as represented in table 1, 2 and 3.

Table 5- ANOVA for transverse shrinkage

Source	Regression Coefficient	Sum of Squares	Mean sum of squares	F-value	p-value
Model	2.55	4.10	0.8206	11.65	0.0352
A-A	0.6811	2.78	2.78	39.51	0.0081
B-B	-0.1007	0.0609	0.0609	0.8642	0.0421
AB	-0.2144	0.1839	0.1839	2.61	0.0204
A^2	0.1619	0.0524	0.0524	0.7440	0.0451
B^2	-0.7149	1.02	1.02	14.51	0.0318
Residual	2.55	0.2113	0.0704	-	-

Regression coefficients were calculated using analysis of variance (ANOVA) testing with Design Expert 11.0 software [9]. Regression coefficients contribute to relationship between response and variables. Higher values of regression coefficient indicate a strong influence among preferred variable on measured response and vice-versa. Whether a positive value of coefficient represents a mutual relationship, negative value represents an inverse relationship between variable and response. F-test and p-test has been conducted to check accuracy of predicted model. P-test was conducted on 5% level of sig-

Table 5- ANOVA for longitudinal shrinkage

Source	Regression Coefficient	Sum of Squares	Mean sum of squares	F-value	p-value
Model	1.07	1.83	0.3667	84.12	0.0020
A-A	0.1403	0.1182	0.1182	27.11	0.0138
B-B	0.5247	1.65	1.65	378.89	0.0003
AB	-0.0825	0.0272	0.0272	6.25	0.0478
A^2	-0.0030	0.0000	0.0000	0.0041	0.0428
B^2	0.1350	0.0364	0.0364	8.36	0.0329
Residual	0.2113	0.0131	0.0044	-	-

-nificance and found that all the factors are significant as mentioned in Table 4. P-values less than 0.0500 indicate model terms are significant [10]. Following mathematical equations were obtained by placing the values of regression coefficient in mathematical model as mentioned in equations 3 and 4.

$$\text{Transverse shrinkage} = 2.55 + 0.655(A) - 0.1007(B) - 0.2144(AB) + 0.1619(A^2) - 0.7149(B^2) \quad (3)$$

$$\text{Longitudinal shrinkage} = 1.07 + 0.1403\,(A) + 0.5247(B) - 0.0825\,(AB) - 0.003\,(A^2) + 0.135(B^2) \quad (4)$$

5. CONCLUSION

Crafted mathematical equations can be employed as an predictive tool for quantification of transverse and longitudinal shrinkage for a give range of weld- groove angle and plate thickness. Following conclusions are also observed.

1. Influence of groove-angle was more prominent than plate-thickness in transverse shrinkage, at the one side transverse shrinkage increases with groove angle whether effect of plate thickness was found inverse. Effect of groove angle was less prominent for longitudinal shrinkage in compare to plate-thickness. It had been evident that by increasing both the parameters longitudinal shrinkage in mild steel increases.

2. The Model F-value of 11.65 implies the model is significant for Transverse shrinkage. There is only a 3.52% chance that an F-value this large could occur due to noise. The predicted coefficient of determination (R^2) of 0.8242 is close to the adjusted coefficient of determination (R^2) 0.8694 as one might normally expect; i.e. the difference is more than 0.2. Adequate precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 10.109 indicates an adequate signal.

2. The Model F-value of 84.12 implies the model is significant for longitudinal shrinkage in Mild steel. There is only a 0.20% chance that an F-value this large could occur due to noise. The predicted coefficient of determination (R^2) of 0.9138 is in reasonable agreement with the adjusted coefficient of determination (R^2) of 0.9811; i.e. the difference is less than 0.2. Adequate Precision of 24.671 indicates an adequate signal. That indicates both mathematical models can be used to navigate the design space.

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