Numerical Modeling and Experimental Validation to Control arc Weld Induced Angular Distortion

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Abstract—Welding represents one of the most complex manufacturing processes in terms of number of variables involved and factors contributing to the final output. Welding has been used in the fabrication of structures ranging from conventional industrial applications to high-tech engineering applications in nuclear, aerospace, marine and high-pressure vessel applications. Welding, however, induces thermal strains in the weld metal and base metal regions near the weld, resulting in stresses, which in turn combine and react to produce internal forces that cause bending, buckling, and rotation. These displacements are termed as welding distortions.. As a widely used manufacturing technique, welding offers a number of technical challenges to the welding community specially shop floor engineers engaged in manufacturing of structures integrated through welding. During the joining of components of a structure together by welding, the highly localized thermal gradients from welding result in high magnitude residual stresses of the order of yield strength of the material within and around the weld region, along with significant deformation/distortion of the structures to be welded. Both weld residual stress and distortion can significantly impair the performance and reliability of the welded structures. Therefore, they must be critically dealt with during design and manufacturing phases, to ensure intended in-service use of the welded structures. The scope of this paper is limited to but welding of structural steel plates. One of the major mechanical effect of welding i.e. deformation, will be mainly focused. A model has been established to simulate the transient thermal analysis with moving parallel heat source by using finite element method. Simulation results have been compared to results obtained from actual experimentation. The effect of different parameters such as parallel heating flame distance, heat inputs, temperature distribution has been

Index Terms— Finite element , Transient, Temperature field, Weld pool

I. Introduction

Welding is non-detachable joining or coating of components or base materials under the (mostly local) application of heat or pressure, with or without the use of filler materials (definition according to German standards). Joining is preferably performed with the welding zone being in the plastically deformed or liquid state. Thermal cutting is the separation of components or base material through local application of heat. This chapter refers primarily to (gas or arc) fusion welded joints (seam welds) and to pressure welded joints (spot welds).

Due to highly localized transient heat input, considerable residual stresses (welding residual stress) and deformations (welding distortions, welding shrinkage, welding warpage) occur during and after welding. In contrast to load stress i. e. internal forces being in equilibrium with external forces, residual stresses are internal forces occurring without external forces. The sections and chapters which follow deal mainly with "macroscopic" residual stresses , which are of relevance for the engineer and which can be described in terms of continuum mechanics, whereas "microscopic" residual stresses between or in the crystallites are ignored. Warpage is a phenomenon of structural instability as a result of shrinkage or distortion.

Welding residual stresses and welding distortion may greatly impair manufacturing and strength. Measures are, therefore, taken to minimize welding residual stresses and residual distortion, or to eliminate them after welding. In manufacturing, welding deformations jeopardize the shape and dimensional tolerances required. Joint misalignment and increased groove gaps render manufacturing more difficult. Welds, especially tack welds, may rupture partially or completely as a result of residual stresses produced during welding. Residual stresses relieved during machining result in unacceptable distortions of the work piece. Welding residual stresses may cause brittle fractures in the finished structures. Tensile residual stresses reduce fatigue strength and corrosion resistance. Compressive residual stresses diminish the stability limit. In contrast, the positive effects of welding residual stresses (compression is favorable in respect of fatigue and corrosion; tension is favorable in respect of stability) are of secondary practical significance.

This state of affairs results in structuring of the material into following principal sections:

- Welding temperature field analysis,
- Welding residual stress and distortion analysis,
- Reduction of welding residual stress and distortion,
- Effects of welding on strength.

The analysis of welding residual stresses and of welding distortion, viewed in a historical perspective, developed to a large extent independently of each other although, viewed from physical aspect, they are closely related. This is based first of all on the fact that welding residual, stresses are primarily of interest as a basis for accessing strength, whereas welding deformations, by contrast, are primarily considered as phenomenon impairing manufacture. However, a methodical difference also exists in respect of physics in that it is generally necessary to develop a finite element model of the structure for assessing welding residual stresses, where as simpler approaches within the framework of common engineering theories of structures very often suffice for assessing welding deformations. The assumptions which have to be introduced in the later case relate, in particular, to the magnitude of weld shrinkage force and extension of plastic zone. Welding residual stress analysis, though, can provide reference values of these parameters. If, on the other hand, an approach based on measurement is adopted, this then necessitates sophisticated measuring techniques for welding residual stresses which are practicable only under laboratory conditions, whereas welding deformations can measured under workshop conditions using simple equipments.

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Finally, complete content and organizational editing before formatting. Please take note of the following items when proofreading spelling and grammar.

7.1 EXPERIMENTAL PROCEDURE

Selection of material:- Base metal-The base metal used in this experiment is mild steel.

Table 1: Chemical composition of the Mild Steel

C%	Si%	Mn %	P%	S%	Ni%	Cr%	Fe%
0.1	0.17	0.4 5	0.1 7	0.06	0.132	0.0156 7	98.84

Filler rod details-

Size: 4mm x 350mm.

current range: 150-180 amp

The specimens were with the dimensions of 200 mmX100 mmX12 mm using profile cutting machine and grinding machine.

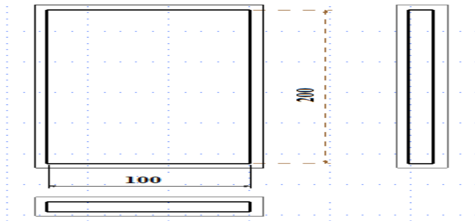

fig 1: Specimen

2 Preparation of V-Grooves:-

V-Groove of angle 30^0 for each specimen was made. Total V-Groove angle 60^0.

3 Preparation of specimens:-

Vertical milling machine and shaping machine were used for preparation of V-Grooves.

4 Positioning of thermocouples :-

In order to measure thermal cycles four holes on each plate of dia. 5 mm & depth 8 mm were made in transverse and diagonal directions as shown in fig. 7.3 (a) and (b) respectively.

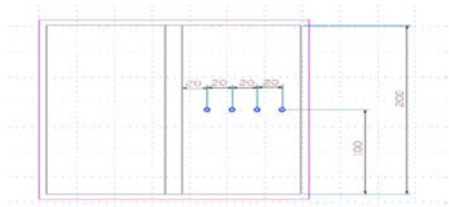

Fig 2: Transverse position of thermocouple

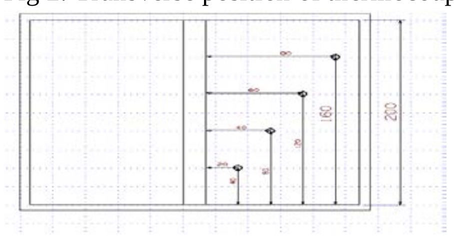

fig 3: longitudinal position of

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thermocouple

5 Removal of stresses (Annealing):-

The induced stresses due to thermal cutting and mechanical works on the specimen are removed by heating the specimens in the furnace up to 750^{0}C.

Later on specimens were cooled up to atmospheric temperature in the furnace.

6 Preparation of parallel heating mechanism:-

A special type of mechanism containing two parallel heating flames were mounted on pug cutting machine as shown in fig 7.4 (a) & (b).

Fig 4: moving heat flame mechnism

7 Transient temperature measurement:-

Four reference holes were drilled on the specimen as shown in fig. 7.5 (a) & (b). Thermocouples were placed in transverse and diagonally direction and temperature measurement was done.

Fig 5: Transverse position temperature Measurement

Fig 6 Longitudinal position temperature

8 Measurement of angular distortion

Angular distortion of plain welded & PHW plates was measured by using dial gauge indicator at the points as shown in

Sr no	Cur rent	Volt age	Time require For 200mm distance.(sec)	Travel speed	Heat Input
1	150	75	52.48	3.81	2509
2	160	75	61.67	3.24	3148
3	170	75	71.41	2.80	3870
4	180	75	67.47	2.96	3876
5	185	75	67.39	2.98	3957

fig. 7.7

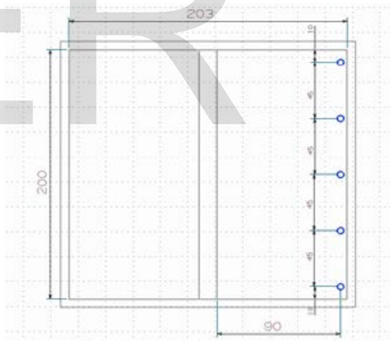

Fig 7 distortion measurement point

Results and discussion

This experimentation is limited to prediction of angular distortion and simulation of parallel heat welding and conventional welding. So the simulation results are validated by actual experimentation. Following graphs shows the comparison of results

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Comparison Between parallel heat welding and conventional welding

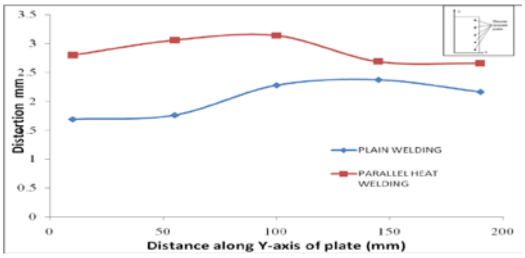


Fig 8.1 Measured angular distortions of points in the Y direction along the edge parallel to weld line when heating flames is at 50 mm.

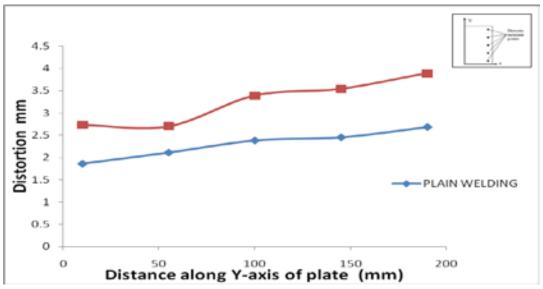


Fig 8.2 Measured angular distortions of points in the Y direction along the edge parallel to weld line when heating flames is at 60 mm.

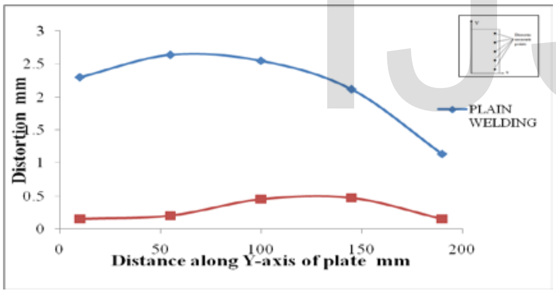


Fig 8.3 Measured angular distortions of points in the Y direction along the edge parallel to weld line when heating flames is at 70 mm.

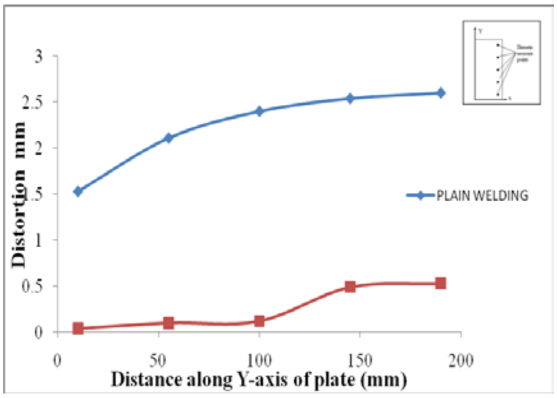


Fig 8.4 Measured angular distortions of points in the Y direction along the edge parallel to weld line when heating flames is at 80 mm.

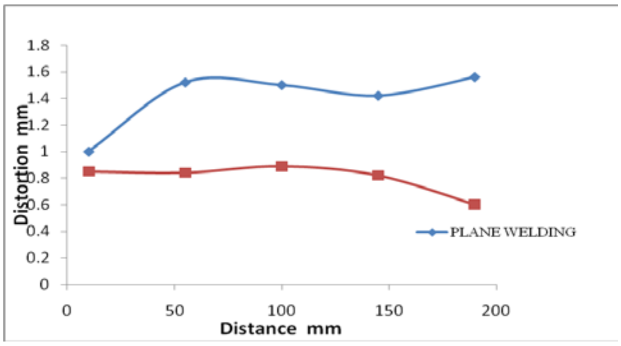
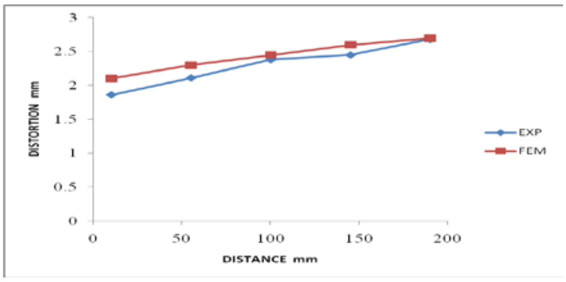


Fig 8.5 Measured angular distortions of points in the Y direction along the edge parallel to weld line when heating flames is at 90 mm.

Fig 8.1 and 8.2 shows measured angular distortions in the Y-axis and the distortion measurement points along X-axis when heating flames is at 50 mm and 60mm from the weld line. The angular distortion of the plate during conventional (plain) welding is less compared to that of the parallel heat welding. This is due to increase in temperature difference between the fusion zone and the edges of the plates because the flame nozzles are close to weld line.

Fig 8.3 to 8.5 shows measured angular distortions in the Y-axis and the distortion measurement points along X-axis when heating flames is from 70 mm to 90 mm from the weld line. The angular distortion of the plate during parallel heat welding is much less as compared to conventional (plain) welding. This is due to decrease in temperature difference between the fusion zone and the edges of the plates.

Comparison of conventional welding with FEA



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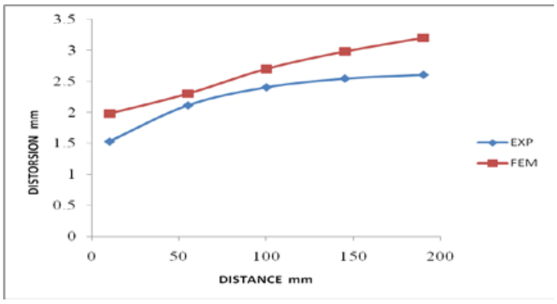

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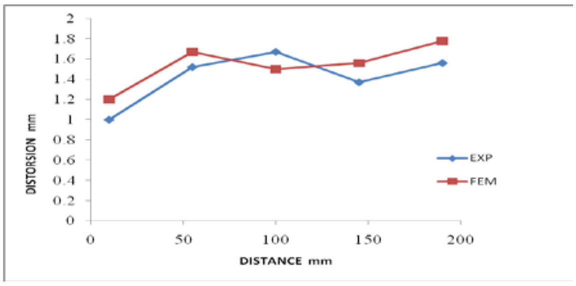

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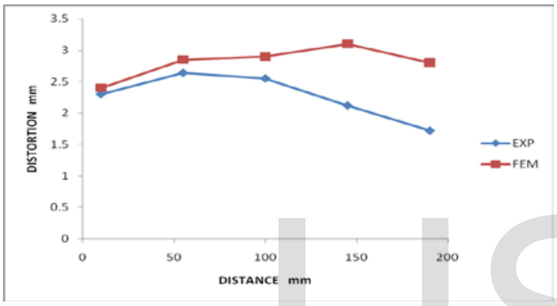

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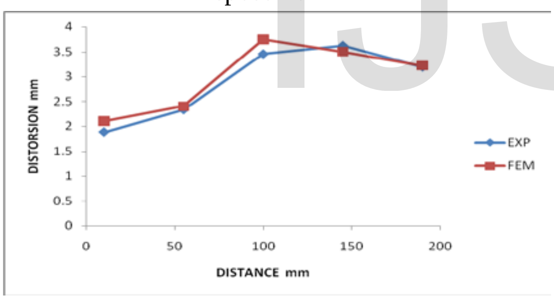

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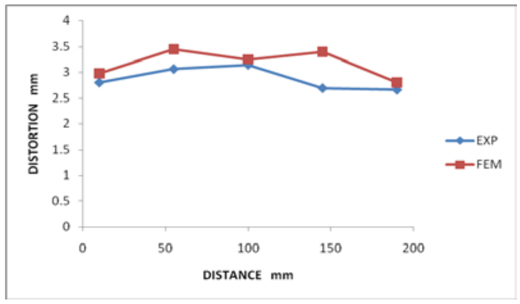
Fig. 8.6 Angular distortion verses distortion measurement point for specimen 1, 2,3,4,5 for plane welding Fig 8.6 Shows measured angular distortions in the Y-axis and the distortion measurement points along X-axis.

From the above graph it is concluded that the FEM result are in good agreement with experimental result for plane welding.

Comparison of Parallel heat welding with FEA



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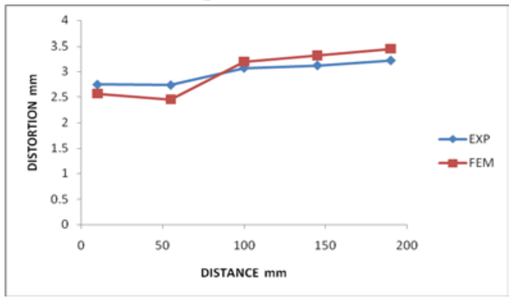

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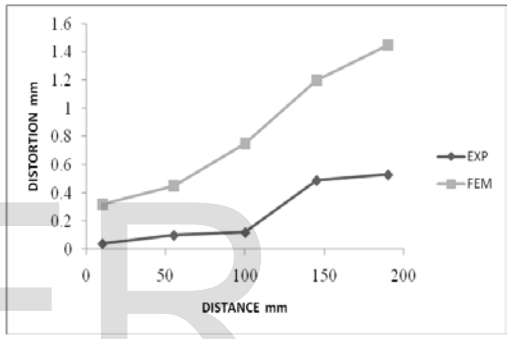

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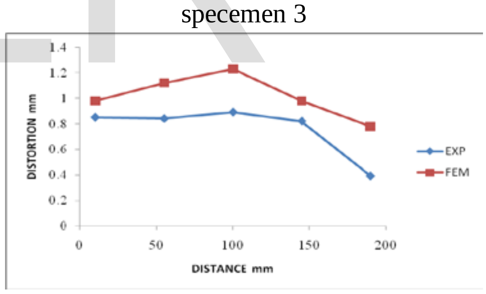

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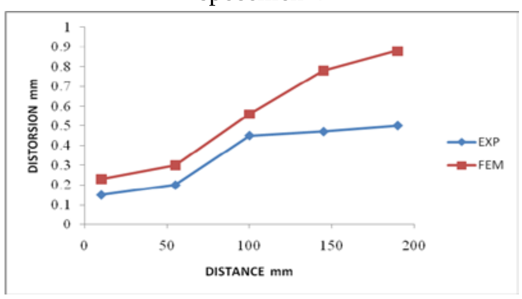

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Fig. 8.7 Angular distortion verses distortion measurement point for specimen 1, 2,3,4,5 for parallel heat welding

Fig 8.7 shows measured angular distortions in the Y-axis and the distortion measurement points along X-axis. From the above graph it is concluded that the FEM result are in good agreement with experimental result for parallel heat welding.

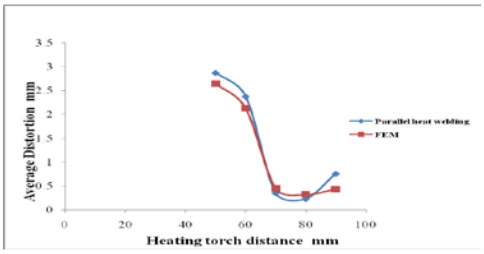

Fig. 8.8: Distortion verses heating torch distance Average from weld line.

Fig.8.8 shows the relationship between avarage Angular distortion and Distance of heating flame nozzle from weld line .It has been observed that when we are providing parallel heat with increasing distance from welding line, the distortion goes on reducing. This is due to the fact that when we provide the parallel heat, the temperature gradient is gradient goes on reducing. Similar pattern is also obtained in case of parallel heat welding simulation.

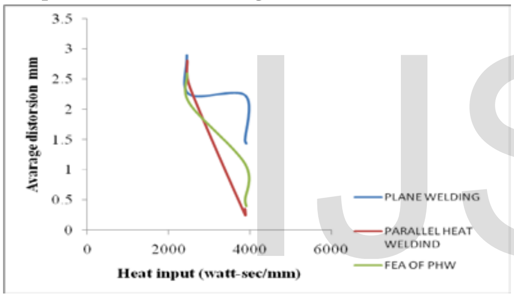

Fig.8.9. Average distortion verses heat input

Fig.8.9 shows the relationship between avarage Angular distortion and heat input.It has been observed that with increasing heat input the average distortion goes on reducing both in case of plane welding and parallel heat welding. Initially distortion in case of both plane welding and parallel heat welding are near about same because heating flame are near to weld line. For the same heat input with increasing heating flame distance from weld line the distortion obtain in case of parallel heat welding is much less as compare to plane welding. Similar pattern is also obtained in case of parallel heat welding simulation

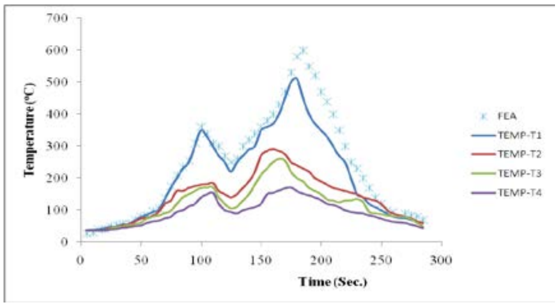

Fig.8.10 Temperature verses time in second.

Fig 8.10 shows the relationship between temperature distributions in the plate of the with respect to time. It is concluded that the temperature in the fusion zone (FZ) is high when the welding torch passed during first pass of the welding then it decreased rapidly with time .The temperature again increases rapidly during next pass of welding and again decreases that is process is quasi stationary. . However, in the areas far away from the heating center, the effect of the heat decreases very fast. Similar temperature distribution obtain in case of FEA.

Conclusions

In this study both experimental method and simulation are used to control angular distortion in the butt weld. The conclusions are summarized as follow:

- In case of parallel heat welding, as we increase the nozzle distance from weld line distortion goes on decreasing due to decrease in the temperature gradient and these results are in good agreement with simulation result.
- For the same heat input the distortion obtains in case of parallel heat welding is much less as compare to conventional welding. The results shows agreement of model with actual experimentation values.
- The temperature distribution results shows similar nature for both simulation and actual experimentation.

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