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Distortion Analysis of MAG welded IS2062 Steel Structure

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Abstract: An exploration was performed to investigate the impact of holding location and weld sequence on MAG (Metal Active Gas) welded fillets structure of IS2062. Welding of steel suffers a variety of distortions in both longitudinal and transverse direction, as it is a crucial manufacturing process. This distortion occurs in welding as a result of localize elevation and then retardation of temperature which may be the source of developing interior flaws and also misalign the plates. Therefore, it's become necessary to predict and reduce the distortion in weld components for modifying the excellence of welded structures. For exactly finding of the distortion, analytical approach dependent on 3D FEM for the investigation of MAG welded component with fillet weld is explored. The multifarious process of arc welding is mathematically explained by coupled transitory and nonlinear thermomechanical examination using simufact. welding 5.0.1. The accuracy of the thermo-mechanical simulations is authentically concluded via experimentation for distortion and heat spreading.

Keywords: FEM; Welding Simulations; Distortions; MAG, Fillet Joint, IS2062 Steel

1. Introduction

The most popular MAG welding method is extensively practiced in almost all applications like ship building, defence, automobiles, bridges, construction of machines, nuclear reactors, aerospace etc. in terms of excellent mechanical properties of joints and high productivity. Distortions can be especially challenging in the assembling of sub-structures. Unnecessary distorted elements produce disarrangement of sections and repeatedly entails expensive corrective procedures for decreasing the distortion up to an acceptable value.

Thermal stresses arise in the welding zone and HAZ because of the uneven expansion and shrinkage by increasing high temperature in melting and irregular decreasing of temperature in solidification phases throughout weld joining, resulting in development of the strains continuously and encourages twisting in the metal. The tension and compression succeeding after those strains responds to produce intrinsic stresses that creates different types of distortions[1].

Numerous investigators have made brilliant efforts in identification of various residual stresses and distortion in the weld joints. Still these predicating methods are not able for deciding the sequence of welding for minimization of weld deformations. Hence, it becomes essential to search and find the optimized weld sequence for minimization the deformation.

Park et al.[2] proposed JRM to examine the influence of weld sequence on the deformation and validated the proposed method through experiments and equivalent load method. They also reported that the generated contour in fillet welded deformation was prominently influenced by fixing. Liam Gannon et al. [3] investigated the deformation caused through GMA welded fillets of steel for 4 dissimilar weld arrangements and influence of them on the joint strength. Most preferred welding sequence with least distortion have all four welding directions towards the end from the mid of plate and sequence is diagonally opposite to each other. Deng et al. [4, 5] explains that welding sequence tremendously effect the buckling distortion.

Long et al.[6] predict the distortion of MIG welded HSLA (high strength low alloy) steel plates. The thermal investigation outcomes display that the alteration of heat input constraints disturbs highest temperatures in the various zones of weldment. Liang et al.[7] proposed an innovative technique created on inverse analysis to acquire the intrinsic distortion in a fillet weld joint and recognized that it can precisely estimate the entire weld distortion. The elastic FE study takes little duration to accomplish, which is a very significant benchmark for performing engineering investigations.

Non-uniform expansion and shrinkage in fusion zone of weld is not only the reason for distortion in assembly of components but other controllable parameters are also very significant and should be considered in weld planning as displayed in Fig 1 and three key outlines to explain the weld distortion problems in design, manufacturing and final distortion correction are shown in Fig 2 [8]. Mechanical balance control method was also commonly used to reduce welding distortion during welding. Nevertheless, it can create huge residual stress due to strong outer constrains, which has adverse effect on fatigue performance of welds. Jesus Romero et al.[9] and Kadivar et. al.[10] suggested GA for optimization of sequence of weld and identified best and worst sequence for minimum distortion.

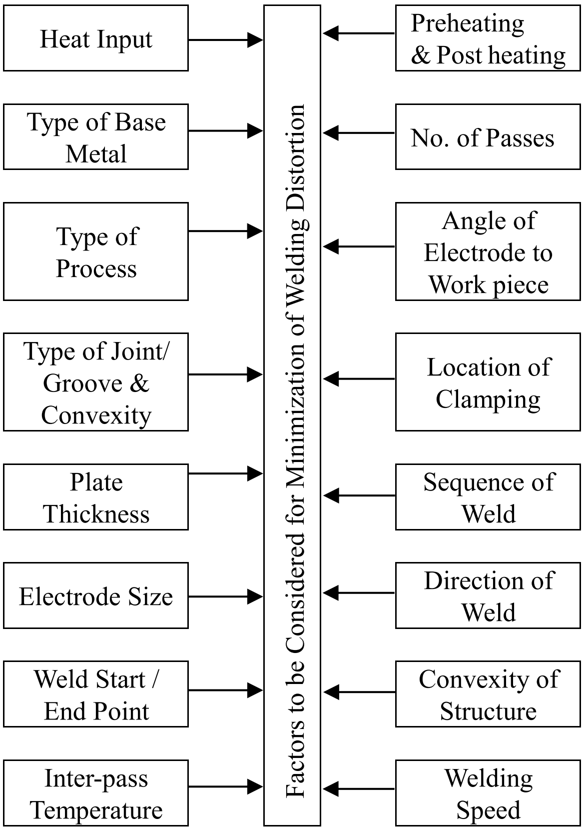

Fig. 1: Process parameters affecting weld distortion

Gaungming et al.[11] examines the distortion of weld T-joints and the outcomes explain that the physical extremities excessively influences the distortion controlling elements. They also concluded that fixation of clamps nearby the edges during weld joining procedure and discharging it afterward cooling to atmospheric conditions will tremendously overcome the geometric imperfections.

El-shrief et al.[12] simulate welding process for 3D sequentially thermal-mechanical analysis in INCONEL718 for calculating the distortion, undesirable stresses and heat profile. They find that for controlling the distortion, the complete weld length of plate should be divided into the steps. The distortion values decrease clearly in four welding steps compared with one-step and two steps. Sequencing in weld is effective tool for controlling the distortion /undesirable stresses.

Ninshu et al[13] calculated the distortion of two enormous assemblies of heavy machines joined by welding individually using and without using jig restraints. The weld distortion of the whole assembly was simulated by FE analysis using IDM. They concluded that the weld distortion can be efficiently foreseen by IDM and the jig restraint was very active in reducing welding deformation.

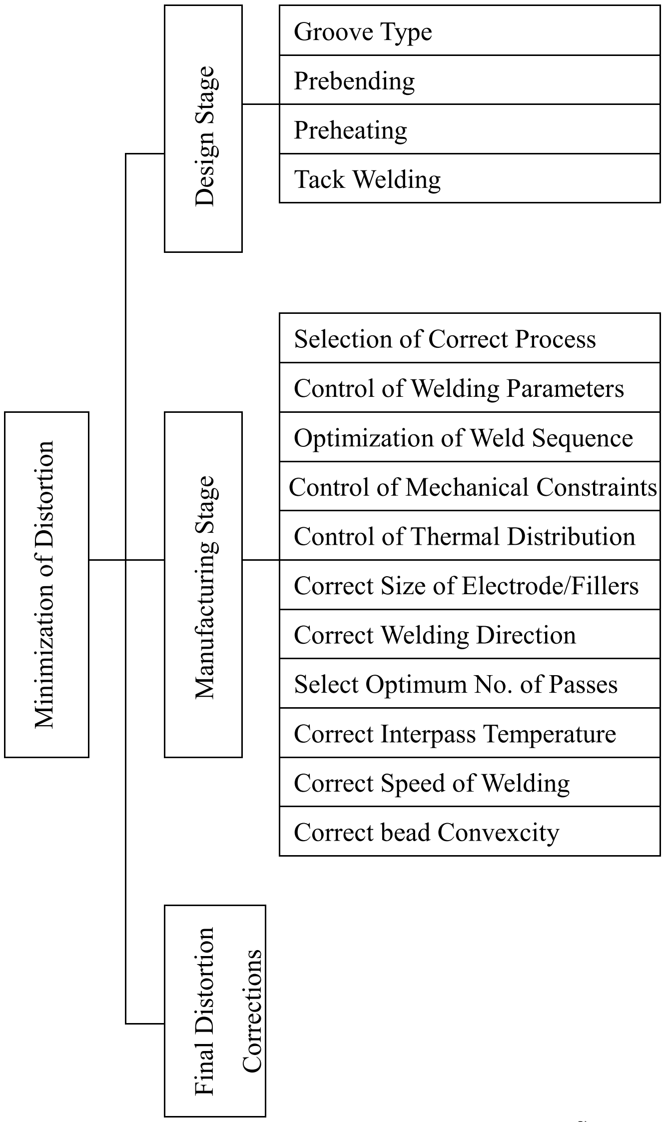

Fig 2: Factors for minimization of welding distortion [8]

Also the jigs nearer to weld center are supportive for reducing distortions. Deng et al.[14, 15] studied weld deformation with FE analysis depending upon intrinsic straining philosophy and interface constituent invention. The outcome of these studies explains that the sequence or order of assembling have a tremendous effect on the ultimate distortions. These inventors as well predict that decreasing heat input, increasing plate thickness & space among stiffeners and proper welding sequence are active techniques to reduce the buckling tendency.

Haung et al.[16] familiarized an adaptable arc stretch regulator for maintaining the best possible combinations of inputs to achieve optimum quality of weld joint and to avoid extreme distortions. Liang et al.[17], Murakawa et al.[18] and Yu et al.[19] declared that order of welds has a great impact on absolute twist distortion. For declining weld imperfection, it is compulsory to practice tack weld procedure for escalating the rigidity of the assembly and also use external clamping for significantly overcoming of the angular distortion.

Sudhakaran et al.[20] optimized GTAW constraints with element cloud method to decrease angular deformation. Experimentally validated results show that the developed model is capable for producing the precise output and minimum angular deformation in SS-202 coupon. Deng et al.[21] and Liang et al.[22] deliberate the effect of exterior restriction on weld distortion in thin-plate and concluded that exterior restriction will mitigate the extent of the ultimate deformation. This study also demonstrate that exterior restriction overcome in-plane as well as out of plane deformation. Park et al.[23] considered the impact of the pre-tensioning stress by considering its release time, the direction and magnitude on weld deformation of thin steel structure and decreases deformations via 40% and 60% in 8 mm and 5 mm thick plate respectively without any exterior force. The angular distortion can be reduced by approximate 25% by holding pre-tensioning stress for one hour after finishing of weld compared to releasing instantly and similar outcome was observed with exterior force on angular distortion.

Tsai et al.[24] introduces the joint rigidity method for finding out the optimal sequence of welding for improving the flatness of the welded plate. Also localizing welds nearer to the neutral axes reduces the distortion and bending of a stiffened panel. Roeren et al.[25] investigate the mechanical influence of the clamps for an overlap joint and they found that the space between clamps affects the ultimate weld distortions. According to them smaller the distance between weld and line, smaller will be total distortion. Also second parameter which influences distortion is the clamp release time.

Schenk et al.[26] had investigated the impact of holding duration, relief duration and preheating of holding device on weld distortions in overlap joint and T-joint. They concluded that use of holding arrangement and extended relief duration relative to duration of cooling can reduce total distortion in welded component. Also heating of holding devices reduces the buckling distortion and adaptive clamping can be fruitful for minimization of final distortion.

Tikhomirov et al.[27] discussed few industrial mock-ups for modelling of weld deformations. These models were compared in terms of number of material parameters required, pre-processing time required, relative accuracy to experimentation and entire calculation duration required on an intricate component. However, thermomechanical-metallurgical models are most accurate but, these models require large number of material data and computation times. Guangming Fu et al.[28] concluded that if weld is performed in the identical track of the prior will encourage the extreme upright deformation. Also, the welding sequence meaningfully effects the extent and deformation manner of the deflections. The influence of holding device on the weld imperfections was investigated by Yashar Javadi[29] in Monel-400 structures. He concluded that clamping has potential to decrease 75% of total distortion in welded component but, at same time increases residual stresses by 10%.

All the above researchers have made very good attempts to minimize/optimize the distortion in simple/small size components or with some moderate fillet weld structures. Very few literature is available for minimization of distortion in complex shaped structures. In this study, an attempt has been made for minimization of the final distortion in a complex shaped carbon steel IS2062 E450 structure by considering the influence of clamping position, welding direction and sequence of welding.

2. Material Properties

Precise thermal and material properties of the used materials must be taken in account to obtain accurate numerical results. All these properties must be measured as functions of temperature and phases. Young's Modulus, thermal strains, Poisson ratio, strain hardening, density, thermal conductivity and latent heat must be known for quality welding. Chemical composition and other mechanical properties of material used for study is presented in Table 1 & 2.

Table 1: Chemical Composition of IS2062-E450

Sr. No.	Element	Percentage
1.	C	0.173
2.	Mg	1.42
3.	Si	0.35
4.	Cu	0.104
5.	Cr	0.133
6.	Nb	0.042
7.	P	0.017
8.	Al	0.024
9.	Fe	97.69

Table 2: Materials Properties of IS2062-E450

Sr. No.	Material properties	IS 2062
1.	Melting point(°C)	1500
2.	Solidus temp (°C)	1450
3.	Latent heat (mm^2/s^2)	2.564e+11
4.	Poisson's ratio	0.283
5.	Density (kg/mm^3)	7855
6.	Yield Stress (MPa)	532.1
7.	Tensile Stress (MPa)	693.5

3. Heat Input

Heat input parameters has great importance in analysis of welding distortion. Heat input parameters of this investigation were selected on the basis of literature survey[6] and trial & error method. The parameters of welding are shown in Table 3. For MAG welding, the heat source efficiency was considered to be 80% for this experimental analysis. Volume of deposited material for each bead is determined with electrode size and weld speed. Heat source parameters were calculated as per the Goldak's Double Ellipsoid Model[30] as shown in Fig. 3, which possess the ability for analyzing the heat characteristics of all type of weld bead geometries. Double ellipsoid model provides precise calculations in comparison of others.

Table 3: Heat Input Parameters for IS2062-E450

Sr. No.	Parameter	Values
1.	Electrode	AWS A5.29 E90T5K2
2.	Electrode size	1.2 mm φ
3.	Current Type	DC
4.	Current	200A
5.	Voltage	30V
6.	Efficiency	80%
7.	Welding Speed	5 mm/sec

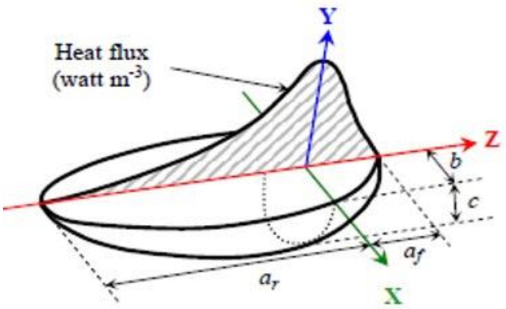

Fig. 3: Heat Source Model

4. Experimentation

Fig. 4 shows the outline for computing the distortion in welding simulation. The base metal used in this experimentation was IS2062:E450. The component under this investigation was a box type structure of dimensions approximately 1 m height, width and length each with 10 mm thick plate as shown in Fig 5. Fillets weld leg length of 5mm were welded by MAG welding. Though electron beam and laser beam welding produce lesser distortion, but they cannot be used for thick plate and big structure application and MIG/MAG welding is widely used because of its merits like ease of use, high diffusion, greater weld speediness (high productivity), excellent bead appearance and small sprinkling.

Torch inclination was supposed to be perpendicular to the upper top of plates. Complete joint was finished in twelve segments / sequences. Heat source parameters were decided as per the recommendations of Haung et al. [16] by considering the distance between work piece and welding gun and are as follows:

- Front Length (af) : 3.0 mm
- Rear Length (ar) : 11.0 mm
- Width (b) : 5.5 mm
- Depth (c) : 8.5 mm
- Heat Front Scaling Factor : 0.461538

Entire model contains 3 configurations: 2 components and 1 weld-seam. Clamps by way of mechanical boundary conditions were employed on the exteriors of the components and the tightening strength was as good as 100 Newton. Clamp stiffness was calculated to be 281487.0 N/mm. The experiments were performed at ambient temperature of 20^0C. The filler material electrode having matching chemical and mechanical properties was used in this experiment.

Model is created using NX9 and then meshed using Hypermesh. One of the most important tasks during finite element modelling is meshing since this one meaningfully influences the correctness as well as computation time. Relatively fine meshes were used near the weld line and the portion far from weld line, the meshing is progressively coarse as shown in Fig. 6. The weld analysis was accomplished by means of simufact.welding (MSC Marc explainer). As simufact.welding© only supports .bdf file format, so hypermesh file is exported in .bdf file format.

First of all, thermal analysis is performed for calibration purpose. Coupled thermo-mechanical approach was used for finding out total distortion in the model. Influences of metallurgical aspect alteration no way deliberated in this investigation. Three different iterations for simulation were carried out by changing welding sequence, number of clamps and clamping positions as shown in Fig. 7 to 11.

5. Results and Discussion

The simulation study was performed on fillet welded IS2062:E450 component with three different welding iterations having different welding sequence and clamping positions. Initially locations of clamps and welding sequence was decided based upon the literature survey and opinions of welding experts with keeping in mind the mechanical balance control[8], best and worst sequence of welding[9,4,5], rigidity of joints[23], type of process, joint design, clamping condition[11,21,22,29], dividing the complete welding into steps[12], bearing location[13] etc. The direction of each sequence was started from the more rigid location and end towards the lesser. The complete structure was tack welded after placing the clamps and before starting the main welding to increase the stiffness[17,18,19]. In other words, firstly weld central stiffener from both sides and then weld the inner joint of the edge stiffeners and, finally at the outermost location.[24].

In the first iteration, the welding sequence, bearing and clamping locations were as shown in Fig. 7, 9 & 10 respectively. The bearing patches are attached to the plate whereas clamps are 50 mm away from the edges of plates. This iteration was run in the software and the total distortion was 2.49 mm as shown in Fig. 12.

In the second iteration, bearing and clamping positions were kept same as in iteration 1 and welding sequence was changed as per Fig. 8. This iteration was also run-in software and found a total distortion of 2.53 mm as shown in Fig. 13. The reason for higher distortion may be earlier weld sequence was started from the lower rigid locations.

On basis of comparison with iteration 1 & 2, it was decided to continue with the welding sequence of iteration 1 because of less distortion. In third iteration, the welding sequence and bearing locations were as per iteration 1 and location of clamps were changed as per Fig. 11, which were 25 mm inside from the outer edges. Accordingly, the iteration was run and maximum distortion was found 1.67 mm as shown in Fig. 17.

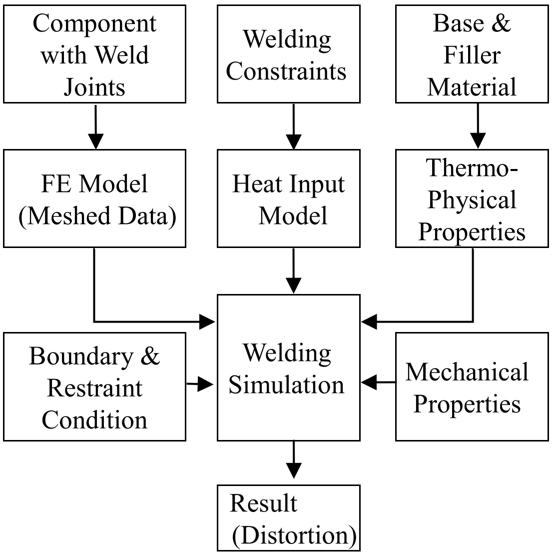

Fig. 4: Outline of Welding Simulation

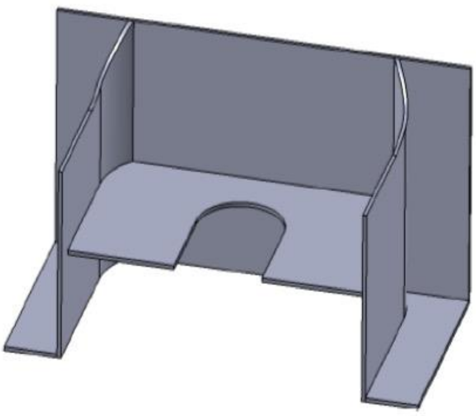

Fig. 5: Component with welding seams

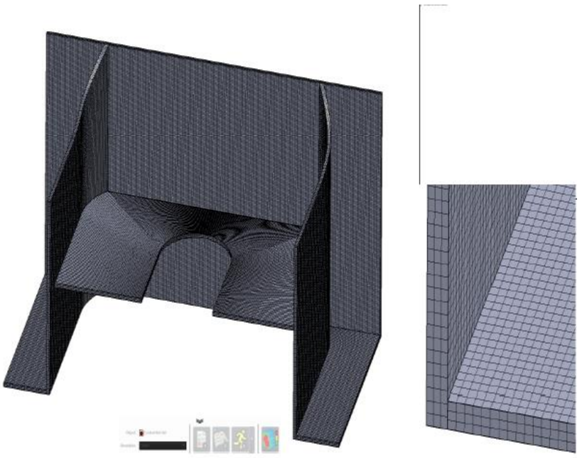

Fig. 6: Meshed Model

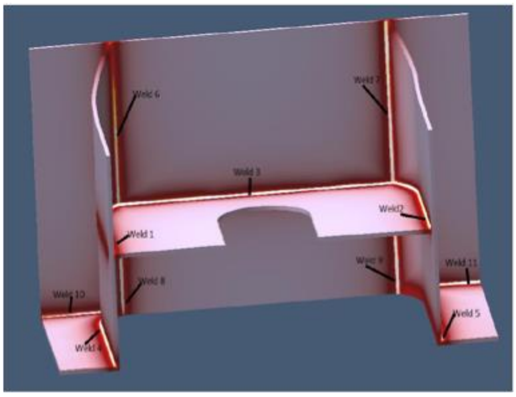

Fig. 7: Welding Sequence for Iteration 1 & 3

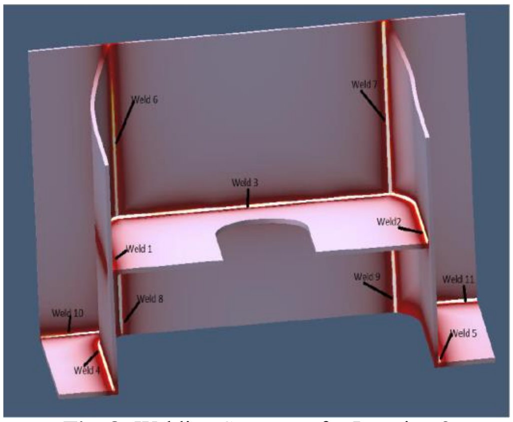

Fig. 8: Welding Sequence for Iteration 2

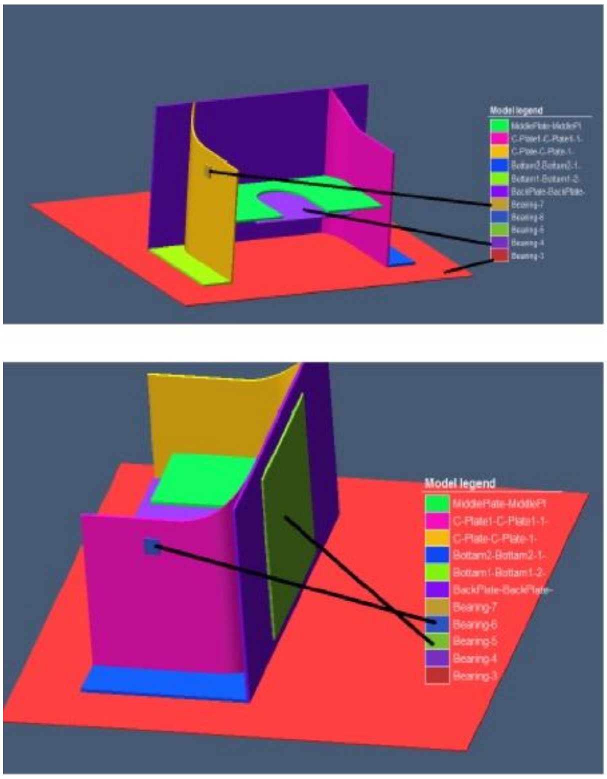

Fig. 9: Bearing Location (Front & Back) for Iteration 1, 2 & 3

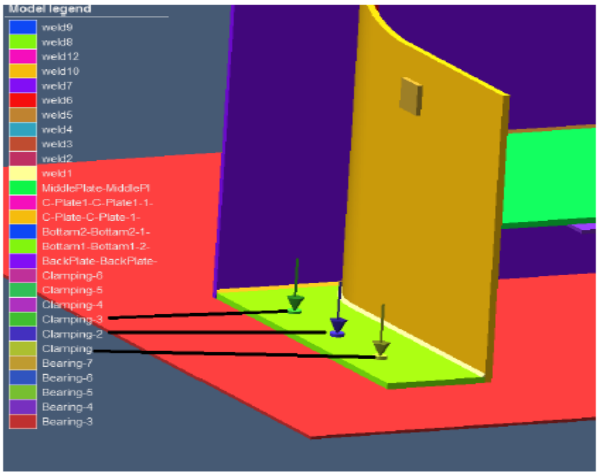

Fig. 10a: Left side Clamping Locations for Iteration 1&2

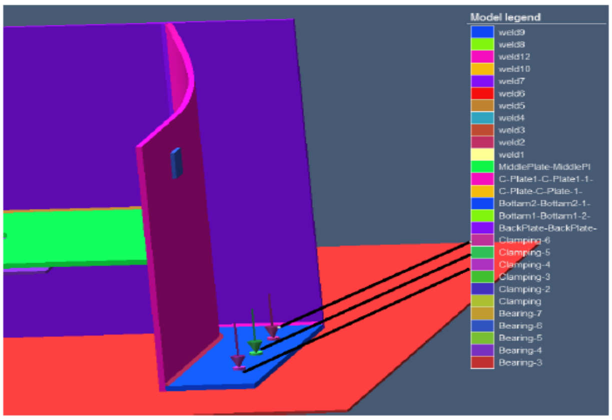

Fig. 10b: Right side Clamping Locations for Iteration 1&2

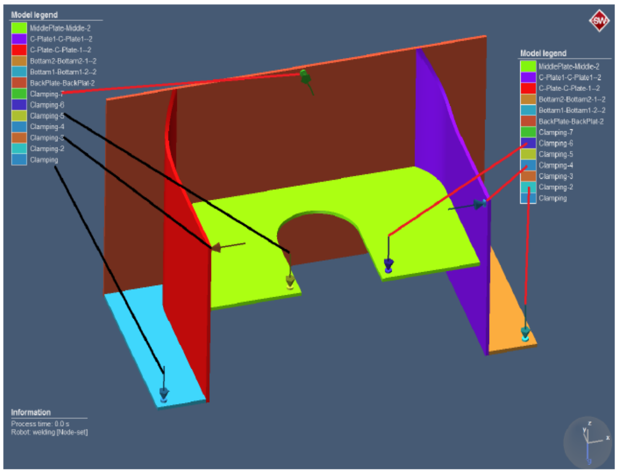

Fig. 11: Clamping Locations for Iteration 3

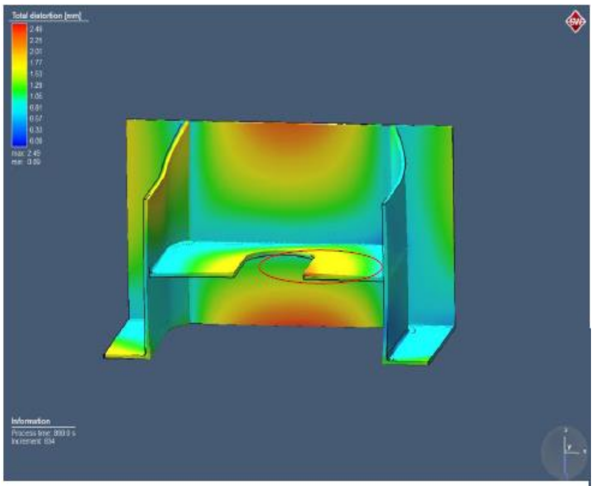

Fig. 12: Total Distortion for Iteration 1

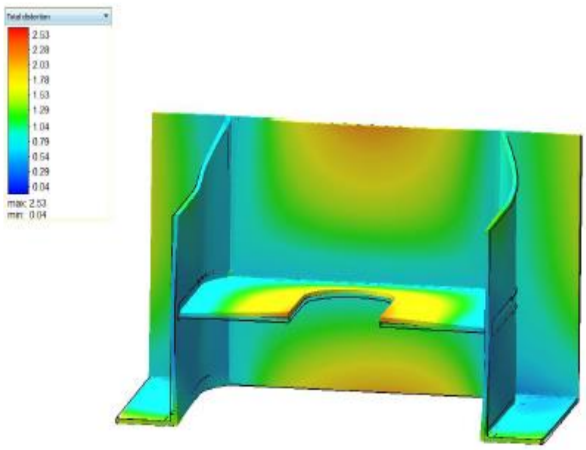

Fig. 13: Total Distortion for Iteration 2

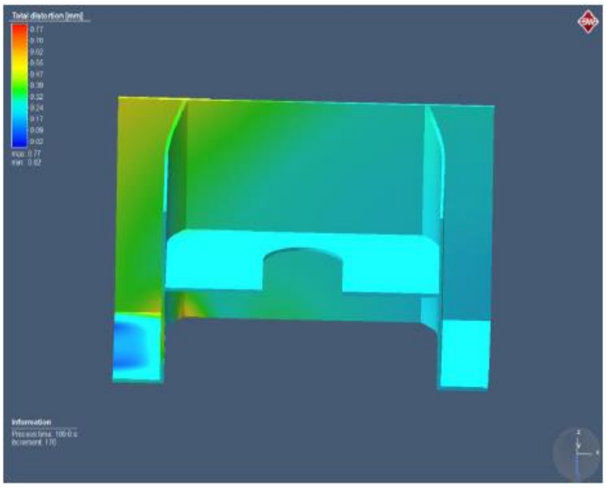

Fig.14: Total Distortion for Iteration 1 after 110 sec

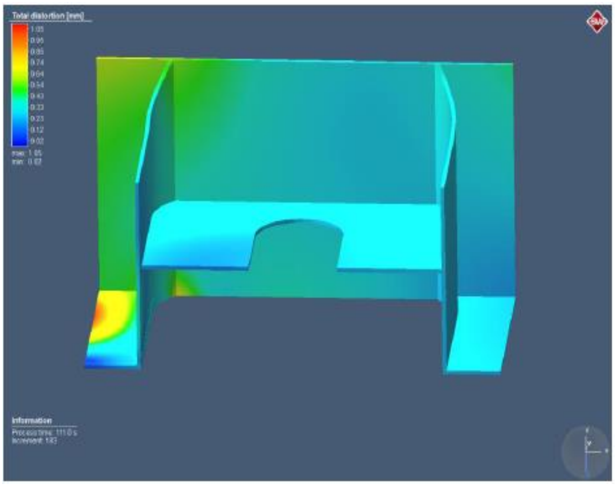

Fig.15: Total Distortion for Iteration 3 after 110 sec

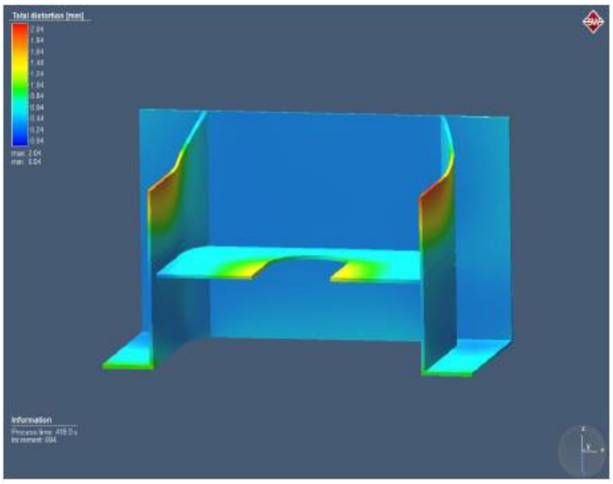

Fig.16: Total Distortion for Iteration 1 after 418 sec

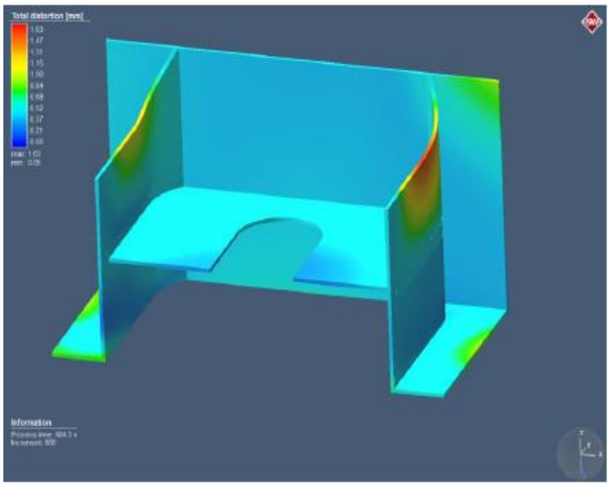

Fig.17: Total Distortion for Iteration 3 after 418 sec

Changing of clamps location in iteration 3 was decided upon the outcome of the highest distorted areas in iteration 1 and 2. Due to locking the movement of highly distorted areas and shifting the location of clamps nearer to edges (50 mm to 25 mm from the corner / edges), lesser deformation was achieved in this complicated structure [11,13]. Distortion of iteration 1 and 3 was also studied with respect to the time lapsed after completion of weld and are shown in Fig. 14 to 17 and gives an idea about the trend / order of distortion with the time after completion of weld. Therefore, clamps were loosed after completion of weld metal solidification, which takes almost 7 to 8 minutes[11,23].

6. Confirmation Test

In the verification of simulated outcomes of iterations, the finishing phase is the cross examination of extracted effects by experiments. Here the verification experiments were escorted by utilizing the parameters of iteration 3 for IS2062. Whole welded structure is divided in 30mm x 30mm grid size and distortion is measured at each corner of grid.

Distortion measurements were carried out by 3D CMM (Three Dimensional–Coordinate Measurement Machine) for the structure before (tack welded) and after welding. Maximum distortions before and after welding were measured as 0.12 mm and 1.84 mm respectively. Experimental values of maximum distortion were very close to analytical values of distortions and hence confirm the validation of results.

7. Conclusions

Welding distortion analysis is highly precision method for prediction of weld distortion by means of computer based numeric investigations at the initial phase of production plan. These investigations facilitate the computer-generated scrutiny of the weld distortion without execution of costly trials. In this article the application opportunities of weld simulation for carbon steel complicated shaped component within the development of manufacturing methods are discussed.

The analysis focus on the simulation of the welding sequences and clamping location and its effect on distortions. Three different iterations were compared and the numerical predictions are verified with measurements of the distortion evolution. Conferring to the investigated outcomes and the investigational extents, followings are the major concluding remarks:

(1) Weld distortions estimated by analytical simulated approach in the component with fillet weld are worthy.

(2) Sequencing of weld passes diagonally opposite to each other and directed towards the free end from rigid one reduces the total distortion.

(3) Placing of clamps nearer to weld line/center helps in minimization of final distortion.

(4) Dividing of weld length into steps and sequencing has significance in the control of distortion in MAG welded components of Carbon Steel.

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Nomenclature

3D	Three dimensional
CS	Carbon Steel
FEM	Finite Element Modelling
GA	Genetic Algorithm
GMAW	Gas Metal Arc Welding
HAZ	Heat Affected Zone
JRM	Joint Rigidity Method
IDM	Inherent Deformation Method
MIG	Metal Inert Gas
MAG	Metal Active Gas

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