TECHNICAL NOTE

THE ANALYSIS OF LONGITUDINAL SHRINKAGE IN BUTT WELD JOINT

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Abstract In this research longitudinal shrinkage of two steel plates with identical thickness that are joint together through butt welding and another steel plate with bead welding. This study begins with the introduction of a model, in which the thermoelastoplastic zones near the weld line is simulated with a thermoelastoplastic flat bar, and full-elastic areas beyond the weld line is simulated with a full elastic springs, by proposing the physical terms of the model and favorite presumptions, the related equations are solved and eventually the conclusion is a relation which can be used to calculate the amount of longitudinal shrinkage with acceptable accuracy.

Keywords Butt Weld Joint, Distortion, Longitudinal Shrinkage, Thermoelastoplastic

چکیده در این تحقیق، انقباض طولی در دو ورق فولادی با ضخامت یکسان که به واسطه جوش لب به لب به یکدیگر متصل شده اند، مورد بررسی قرار گرفته است. بدین منظور مدلی تعریف شده که در آن نواحی ترموالاستوپلاستیک نزدیک خط جوش با یک تسمه ترموالاستوپلاستیک و نواحی تمام الاستیک فراتر از خط جوش با دو فنر تمام الاستیک شبیه سازی شده و با تعریف شرایط فیزیکی حاکم بر مدل و مفروضات مورد نظر و حل معادلات، رابطه ای بدست می آید که می توان به کمک آن مقدار انقباض طولی را با دقت مناسبی محاسبه نمود.

1. INTRODUCTION

In welding process, the heating and cooling cycle causes shrinkage in both base and weld metal and subsequently shrinkage tend to cause distortion in members and/or metal structures. The word distortion means unconventional deformation in the welded structure in several different form or combinedsuch as buckling, bending which results various dimentional changes in metal structures during and after the welding process that leads to disarrange connections and its removal sustains heavy costs.

Longitudinal shrinkage is one of the dimentional changes in parallel butt weld and bead weld joint. It is an important factor in welding sheet metal, because this is the main factor for buckling along the weld line.

Researchers have studied dimentional changes as longitudinal shrinkage by analytical, numerical and finite element methods. The practical experimental methods which have been used for proving the correctness of theorical methods and/or methods themselves, wrote such empirical relations.

In this paper, longitudinal shrinkage was considered in two steel plates which are of equal in thickness (for butt weld), The near weld line zone in this modle have a thermoelastoplastic behavior, A thermoelastoplastic flat bar was used to simulate and in other area of the weld line we have full elastic reaction with a spring. while longitudinal movement process were studied finally on suitable equation for calculating residual longitudinal shrinkage in a butt weld joint and in bead weld is introduced. Comparision of obtained quantities from this method and experimental samples are the other matters which have been studies in this paper.

2. DESCRIPTION OF MODEL AND ASSUMPTIONS

Debated model is shown in Figure 1, in which the thermoelastoplastic zone of two plates is simulated with a thermoelastoplastic flat bar which has 2Lep width, t thickness and L length and the rest of plates which have full elastic behavior are simulated with two full elastic spring with K equivalent spring constant.

In this model physical property is assumed constant; heat flow similar to bidimentional quasi-stationary state and in conforming with Equations 1 and 2, the yield

$$\sigma y = \sigma yo\ [1 - (T/Tm)] \quad (1)$$

$$Ey = Eo\ [1 - (T/Tm)] \quad (2)$$

σyo and Eo are yield stress and modulus of elasticity at room temperature respectively. Tm is melting temperature of metal.

3. ANALYSIS OF MODEL

In heating cycle, the thermoelastoplastic flat bar of model was expanded and resistance forces of springs contract the flat bar, thus, regarding to description of model, the elastic strain of flat bar is written as follows:

$$\varepsilon = \delta/L = \varepsilon e + \alpha T \quad (3)$$

In the Equation 3, αT is thermal strain and εe is elastic strain resulted from resistance force of springs, and:

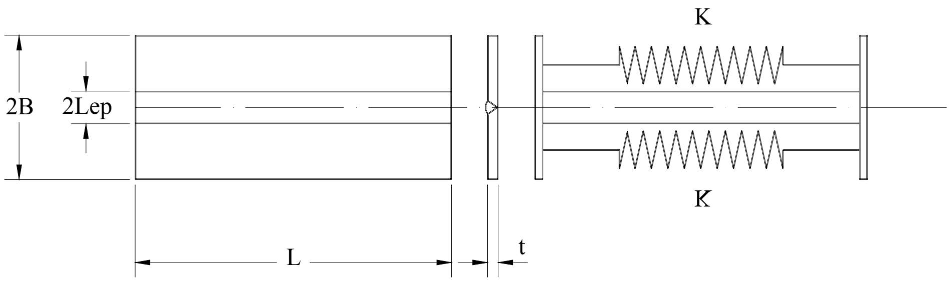

Figure 1. The model of longitudinal shrinkge process analysis.

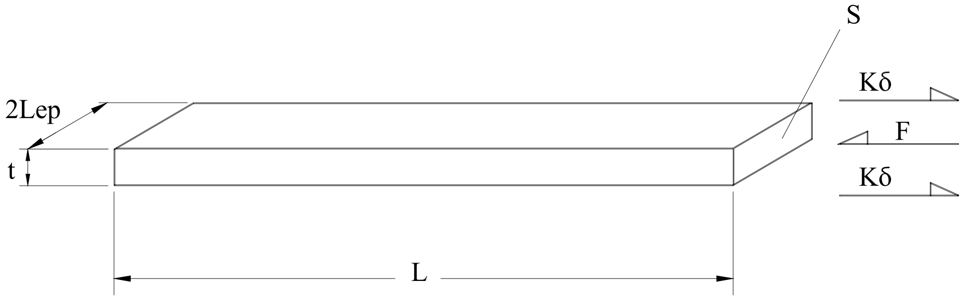

Figure 2. Balance of forces in model.

$\varepsilon e = \sigma/E$ (4)

according to Figure 2, $F = -2K\delta$, (F is spring force), thus:

$\sigma = F/S = -2K\delta/S$ (5)

For easy calculation, dimentionless parameter Kr is defined as follows:

Kr = (spring constant divided by flat bar constant) = (2K) / (EoS/L) (6)

S is cross section of model's flat bar, and is equal with; S = 2t Lep. with intersection of Equations 2,3,5 and 6 together and simpllify we have:

$\delta = [(Tm-T) / [Tm (1+Kr) - T]\ \alpha TL$ (7)

Equation 7 gives the relationship between displacement of model's flat bar and temperature before it attains the plastic state. When the temperature is higher than the yield temperature, the displacement is obtained from Equation 8 as follows:

$\sigma y = \sigma yo\ (1-T/Tm) \rightarrow Fy/S = (Fyo/S)\ (1-T/Tm)$ (8)

Substituting $F = -2K\delta$ into Equations 8 and 5:

$\delta = +\ \delta yo(1-T/Tm)$ (9)

with substituting yield temperature T1 into Equations 7 and 9 and equalizing both obtainded δ from both equations, we have:

$T1 = [(Kr+1)\sigma yoTm]/[\alpha\ Tm\ Eo\ Kr + \sigma yo]$ (10)

When heating the flat bar is finished, the flat bar enters cooling phase and during this stage, if there is no plastic deformation, the strain change will be as follow:

$\Delta\varepsilon = \delta/L - \delta p/L = (\sigma/E+\alpha T) - (\sigma p/E+\alpha Tp) \rightarrow \delta/L-\delta p/L = (\sigma/E-\sigma p/E) + \alpha(T-Tp)$ (11)

{p} index is the indicator of heating phase therefore Equation 9 can be used for calculating δp:

$\delta p = \delta yo\ (1-Tp/Tm)$ (12)

if Equation 11 is substituted by Equations 2, 5 and 12, at last:

$\delta p = \delta yo\ (1-Tp / Tm) - \{[(Tm-T)\ (Tp-T)\alpha L] / [Tm(1+K)-T]\}$ (13)

Equation 13 is reliable in temperatures between T2 and Tp ($T2 \leq T < Tp$), and T2 is elastic to plastic deformation temperature used in cooling phase (Figure 3). During cooling phase, if tension force of springs leads the flat bar to plastic deformation, regarding Equation 9, the amount of displacement can be obtained from following equation:

$\delta = -\ \delta yo(1-T/Tm)$ (14)

The minimum of Kr for the purposes of producing plastic deformation in the flat bar during the heating phase can be resulted when T1 and Tp are of equal amount in relation (10), (T1 = Tp). In this way, Kr is named Krco or critical relative stiffness:

$Krco = [\sigma yo\ (Tm-Tp)] / [(\alpha EoTp-\sigma yo)Tm]$ (15)

In Equation 13, based on Figure 3, if T = 0, then the minimum Kr that causes plastic deformation in model flat bar during cooling phase equals:

$Krc1 = [(2Tm - Tp)\ \sigma yo] / [\alpha\ TmTpEo - (2Tm - Tp)\ \sigma yo]$ (16)

Obviously it is clear that in original model the maximum temperature in the width of 2Lep is distributed unevenly; and by dividing this width into

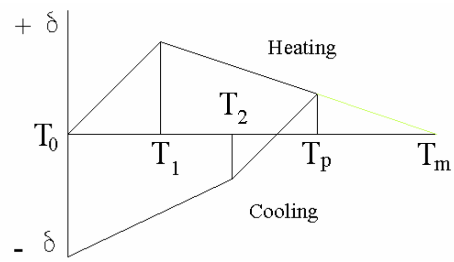

Figure 3. Diagram of displacement - temperature in model.

several strips, the maximum temperature in each strip will be between Tm and Tc(Tm ≥ Tp ≥ Tc).

Tm is steel melting temperature and Te is Lep boundry temperature in each plate which is 350˚C for mild steels [2]. Therefore Lep begins from center of weld line and extends up to the point which its maximum temperature is 350˚C. For calculating the Lep we can use the Adams's maximum temperature equation [3] which has been resulted from Rosenthal's analytic equation [4]. This equation in bidimensional aspect is as following below:

$$1/(Tp-To) = (4.133\ c\rho tvy)/(\eta EpI) \qquad (17)$$

(cρ: Volumetric specific heat, v: Electrode speed, Ep and I: Welding voltage and Current)

Therefore if 350˚C is substitute for Tp, then y equals Lep as coming below:

$$Lep = [(\eta EpI)/(4.133c\rho tv)]\ [1/(350^{\circ}C - To)] \qquad (18)$$

In any situation if we extract Krco and Krc1 from Equations 15 and 16 in temperature, Te = 350˚C and Tm, for a mild steel having average physical properties and constants, it will be as mentioned bellow:

$$Krco \text{ at } 350^{\circ}C \approx 0.3\ /\ Krc1 \text{ at } 350^{\circ}C \approx 1\ /Krco \text{ at } Tm\ ^{\circ}C = 0\ /Krc1 \text{ at } Tm^{\circ}C \approx 0.07 \qquad (19)$$

Kr can be calculated as below:

$$Kr = (2K)/(SEo/L) = [2(B-Lep)tEo/L]/[2LeptEo/L] = (B-Lep)/Lep \qquad (20)$$

If Lep = 0.5B (In welding, actually, Lep is an insignificant fraction of B. thus Lep = o.5B is a inprobable assumption), then Kr = 1. Therefore referring to calculations (19) we can conclude that in heating and cooling phases, plastic deformation in the model's flat bar is observed and the residual shrinkage is calculated with substituting 0 instead of T in Equation 14:

$$\delta r = -\delta yo = -(\sigma yo/Eo)\ (L/Kr) \qquad (21)$$

Therefore we can use Equation 21 if K ≥ 1. When K is grater than 1, the accuracy of equation increases because the constructed model becomes closer and will have more resemblance to the real one. Figure 4 demonstrates a sample of bead weld [5] that has been tried under the conditions mentioned in Table 1. The results of the tests have been put in the same table as the one that shows, if K increases more than 1, the answer's accuracy increas.

Figure 5 shows the distribution of residual longitudinal shrinkage in a sample [5] (in the form of absolute) is 0.515mm that in comparison with δr = 0.6 mm resulted from Equations 20 and 21 is indicator of an acceptable accuracy of equations produced by the model used in this analysis.

4. CONCLUSIONS

In this article, the principle of heat transfer theory has been built on the basis of Rosenthal's bidimentional heat flow theory. Therefore it is expected from the final results of this analysis to have relative and appropiate answer for plates possessing thickness of up to 10 mm. Lengthiness of welding line and the movement of welding electrode at a constant velocity are of the essence in quasistationary state heat flow. quasistationary state heat flow is one of the characteristics of Rosental's analysis, it is possible to use the final equation of this model for welding processes of plates with large dimensions involved in metal heavy industries including shipbuilding.

As shown in Figure 5, respecting this point that the distribution of longitudinal shrinkage doesn't appear to distribute evenly in the width of the plate the relation represented by this analysis at the end, calculates the average quantity of longitudinal shrinkage in the width of the plate (evenly) with satisfactory accuracy.

6. REFRENCES

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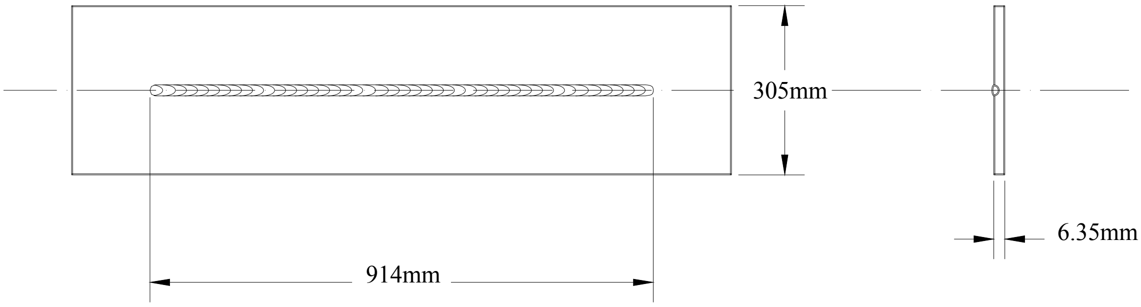

Figure 4. Dimensions of bead weld sample.

TABLE 1. Parameters and Results in Sample of Weld Bead.

Sample	I(A)	Ep(V)	V(mm/s)	Lep(mm)	Krc	δr(mm) Model	δr(mm) Sample
1	100	25	2.5	22.6	5.74	0.28	0.34
2	170	27	2.4	43.3	2.52	0.63	0.54
3	200	30	2.2	61.77	1.47	1	0.70
$\sigma yo = 350$ Mpa, $Eo = 200$ Gpa, $\eta = 0.85$(Arc efficiency), $c\rho = 0.0044$ j/mm ≤							

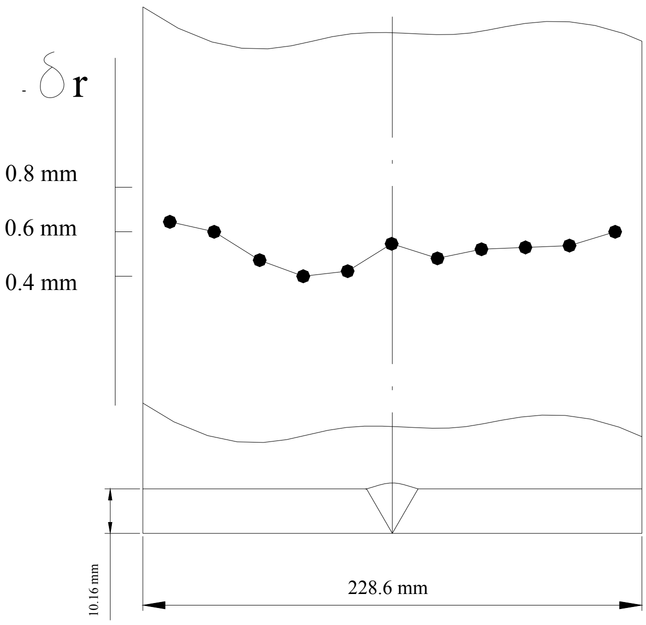

Figure 5. Longitudinal shrinkage distribution in the sample (butt welding)
L = 480 mm, B = 114.3 mm, g = 10.16 mm, Ep = 25 V and I = 260 A.

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