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# The study of longitudinal shrinkage in butt weld joint and weld bead

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## Abstract

This research considers longitudinal shrinkage of two steel plates with identical thickness joined throught butt welding and one steel plate with bead welding . This study begins with the introduction of a model in which the thermoelastoplastic zone near to the weld line is simulated with a thermoelastoplastic flat bar; and full-elastic area beyond the weld line is simulated with a full elastic springs, by proposing the physical terms of the model and favorite presumption; the related equations are solved and eventually the conclusion is a relation that can be used for calculating the amount of longitudinal shrinkage with acceptable accuracy .

## 1 Introduction

In the welding process, the heating and cooling cycle causes shrinkage in both base metal and weld metal and subsequently shrinkage forces tend to cause distortion in members and /or metal structures. The word distortion means unconventional deformation in the welded structure in the form of the combination of buckling, bending and resulted from various dimentional changes in metal structures during and after the welding process that leads to disarrange connections that its removal sustains heavy costs.
Longitudinal shrinkage is one of dimentional change in parallel of butt weld joint and bead weld. It is important in welding of sheet metal , because it is the mean factor to buckling along the weld line .
Researchers dimentional changes as longitudinal shrinkage have studies by analytical, numerical and finite element methods. The experimental methods

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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) by observance model , that in this model , which the near zone of weld line have a thermoelastoplastic behavior , simulation is made by a thermoelastoplastic flat bar ; in further area of weld line which have full elastic reaction with a spring and while longitudinal movement process studied finally on suitable equation for calculation of residual longitudinal shrinkage in 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 figure1; in which the thermoelastoplastic zone of two plates with a thermoelastoplastic flat bar by having 2Lep width , t thickness and L length , the rest of plates which have full elastic behavior; with two full elastic spring with K equivalent spring constant are simulated .

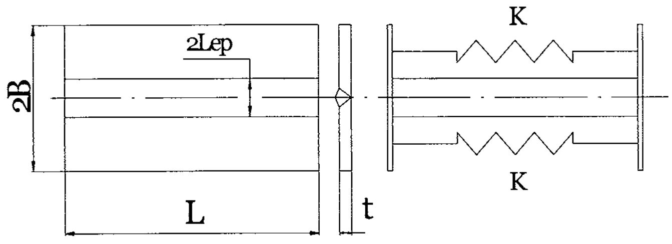


Figure 1 : The model of longitudinal shrinkge process analysis

In this model physical property shall constant ; heat flow similar bidimentional quasi –stationary state and in conforming with equations (1) and (2) , the yield stress and the modulus of elasticity are assumed to be varying linearly with temperature [1] .

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$$\sigma y = \sigma yo\ [1-(T/Tm)] \tag{1}$$

$$Ey = Eo\ [1-(T/Tm)] \tag{2}$$

$\sigma yo$ 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 flat bar is written as follows :

$$\varepsilon = \delta/L = \varepsilon e + \alpha T \tag{3}$$

In the equation (3) ; $\alpha T$ is thermal strain and $\varepsilon e$ is elastic strain resulted from resistance force of spring ; and :

$$\varepsilon e = \sigma/E \tag{4}$$

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

$$\delta = F/S = -2K\delta/S \tag{5}$$

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

$$Kr = (\text{spring constant divided by flat bar constant}) = (2K)/(EoS/L) \tag{6}$$

$S$ is cross section of Model's flat bar, and is equal with ; $S = 2t\ Lep$ . with intersection of equations (2),(3),(5) and (6) to gether an simpllify , we have :

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

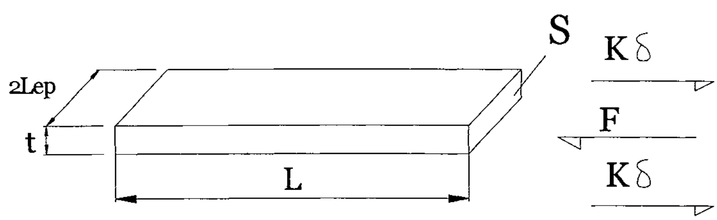


Figure 2 : Balance of forces in model

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Equation (7) gives the relationship between displacement of model's flat bar and temperature befor it attains the plastic sate . when the temperature to be higher than the yield temperature ; displacement obtain from equation (8) as follows :

$$\sigma y = \sigma yo\ (1\text{-}T/Tm)$$

$$Fy/S = (Fyo/S)\ (1\text{-}\ T/Tm) \qquad (8)$$

Substituting $F = -\ 2K\delta$ in to equations (8) and (5) :

$$\delta = \pm\ \delta yo(1\text{-}T/Tm) \qquad (9)$$

with substituting yield temperature T1 in to equations (7) and (9) and equalize both obtainded $\delta$ from both equations ; we have :

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

When heating the model's flat bar is finished ( the end of welding in real one ), the flat bar enters cooling phase and during this stage , if there is no plastic deformation , the strain change will be as following below :

$$\Delta\varepsilon = \delta/L\ -\ \delta p/L = (\sigma/E + \alpha T) - (\sigma p/E + \alpha Tp)$$
$$\delta/L\ -\ \delta p\ /L = (\sigma/E\ -\ \sigma p/E) + \alpha(T\text{-}Tp) \qquad (11)$$

{p} index is the indicator of heating phase left,there fore the equation(9) can be used for calculating $\delta p$:

$$\delta p = \delta yo\ (1\text{-}Tp/Tm) \qquad (12)$$

if the equation (12) is substituted by equations (2) , (5) and (12) , at last :

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

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

$$\delta = -\ \delta yo(1\text{-}T/Tm) \qquad (14)$$

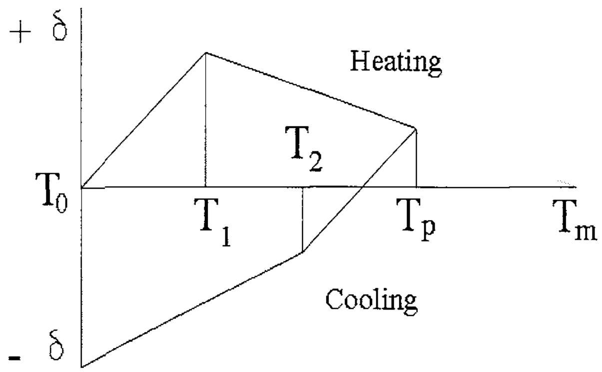


Figure 3 : Diagram of displacement – temperature in model

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:

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

In equation (13) , regarding figure (3) , if T=0 , then the minimum Kr that causes plastic deformation in model flat bar during coolingf phase equals :

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

Obviously it is clear that in original model the maximum of temperature in the width of 2Lep is distributed unevenly ; and by dividing this width up in to several strips , their maximum of temperature 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]. So , it can be stated that in each plate the Lep distance from joining line (center line of weld line) is up to thepart of the plate in which maximum 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 :

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

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

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

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

Krco in 350°C ≈ 0.3
Krc1 in 350°C ≈ 1
Krco in Tm °C = 0
Krc1 in Tm°C ≈ 0.07 (19)

Kr can be calculated as comes 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 improbable 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) :

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

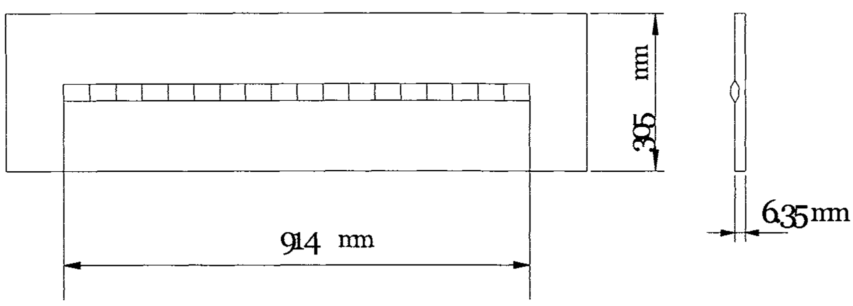


Figure 4 : Geometrical properties in sample of weld bead

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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 , $\eta = 0.85$ , $c\rho = 0.0044$ j/mm$^3$

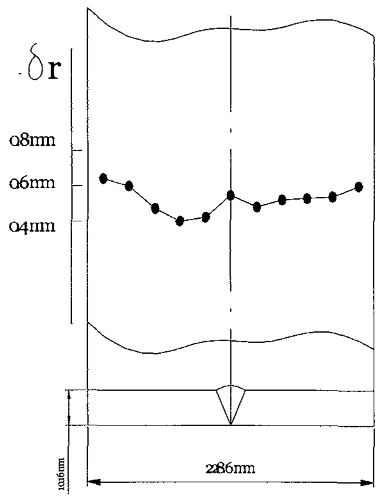


Figure 5:Longitudinal shrinkage distribution in the sample (butt welding)
L = 480mm , B = 114.3 mm , g = 10.16 mm , Ep = 25 V and I = 260A

Therefore we can use equation (21) if $\underline{K \geq 1}$ : and the more $\underline{K}$ is grater than $\underline{1}$ , the more accuracy of equation increases because the constructed model becomes closer and more resemble to real one . Figure (4) demonstrates a sample of bead weld [5] that has been tried under conditions mentioned in table (1).The results

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of the tests which have been put in the same table shows that with K increasing rather more 1 , the answer accuracy increases .
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 $\delta r = 0.6$ mm resulted from equations (20) and (21) is indicator of an acceptable accuracy of equations produced by the model of this analysis.

## 4 Conclusion

In this article , the principle of heat transfer theory has been built on the basis of Rosenthal's bidimentional heat flow theory. There fore it is expected that the final relation resulted from this analysis yields appropriate answer in the plates possessing thickness to 10mm. Regarding to the point that lengthiness of welding line and the movement of welding electrode at a constant velocity are of the essence in quasistationary state heat flow and quasistationary state heat flow is one of the characteristics of Rosenthal'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 to this point that the distribution of longitudinal shrinkage doesn't appear and 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 plate (evenly) with satisfactory accurac

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