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Influence of Butt Welding Shapes Design on the Microstructure and Stresses of Low Carbon Steel

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Abstract

The aim of this paper is to demonstrate the influence of butt welding shapes on the microstructure, temperature and equivalent stresses of carbon steel type St-37.The single butt welding was performed by V angles 15°,30°,45° and U shape. The finite element analysis via ANSYS software is performed , this analysis includes a finite element model for the thermal and mechanical welding simulation. The equivalent stresses and temperature distribution were obtained. From the results of the microscopic structure it is evident that the geometric shape has an important role in the welding process, when the geometric value of the welding region gets bigger, the faults get less due to increase of heat quantity in the welding region. The work presents the finite element model for numerical simulation of welding stresses in carbon steel St-37 butt welding. The welding simulation was considered as a direct coupled thermo- mechanical analysis

Keywords: Welding Technology , Finite Element Method, Heat Transfer, ANSYS software.

تأثير تصميم وصلة اللحام التناكبي على البنية المجهرية والاجهادات للفولاذ المنخفض الكربون

الخلاصة

في هذا البحث تم دراسة تأثير نوع وصلة اللحام على البنية المجهرية والاجهادات المكافئة وتوزيع درجات الحرارة لفولاذ كاربوني نوع St-37 حيث تم اللحام على وصلات تناكبية اجريت لها عملية تحضير بالزوايا V(15°,30°,45°) وبالاضافة الى حرف U من جهة واحدة. تم استخدام طريقة العناصر المحددة من خلال برنامج ANSYS لتحليل عملية اللحام، وهذا التحليل تضمن التحليل الحراري والميكانيكي لمنطقة اللحام حيث تم حساب توزيع الاجهادات المكافئة ودرجات الحرارة لمنطقة اللحام . وقد تم استنتاج ان شكل منطقة اللحام لها تأثير كبير على البنية المجهرية لمنطقة اللحام حيث كلما كبرت منطقة اللحام فان العيوب سوف تقل بسبب زيادة كمية الحرارة في منطقة اللحام وتضمن البحث تحليل منطقة اللحام باستخدام الطريقة المزدوجة المباشرة للتحليل الحراري– الميكانيكي.

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Introduction

The butt welding is a process that is being widely used in industry for sheet joining purposes. Many applications of welding made of carbon steel (e.g. bridge structure, fuel tanks ..etc) are subjected to various stresses (tensile, compressive, bending ..etc). The toughness and resistance of the welded piece to failure depending on many factors such as shape, design of the welding piece, the method implemented for welding and the nature of the applied stresses. Also butt-welding is widely used in automotive industries to assemble various products . It is well known that the welding process relies on an intensely localized heat input, which tends to generate undesired residual stresses and deformations in welded structures, especially in the case of thin plates[1]. Therefore, estimating the magnitude of welding deformations and characterizing the effects of the welding conditions are deemed necessary. With modern computing facilities, the finite element technique has become an effective method for prediction and assessment of welding stresses [2]. Therefore, rapidly and accurately predicting welding induced distortion for real engineering applications is more challenging.

MIG process is considered the most important of such processes due to its easy applications on a wide range of ferrous and non-ferrous metal welding. The required heat for melting is generated by arc due to contact of the welding poles with the work piece. Its quantity depends on the current, voltage and welding speed. Hani [3] (1998) explains that a thermomechanical model was developed using FE method to calculate temperature, stresses and distortions during elasto-plastic analysis. Lindergen et al [4] (2002) presented a thermo-mechanical analysis in butt welding of copper canister for spent nuclear fuel. Anas and Abid [5] (2004) studied the finite element volume for modeling welds and it depicts a brief history of the simulation of welds. Dragi and Ivana [6] (2009) studied the finite element analysis of residual stresses in butt welding of two similar plates.

This paper describes the microscopic structure of welded region and the modeling of the welding process using the finite element modeling technique, three dimensional thermo-mechanical model will be used to model this process.

Experimental

Choice of Metals

Low carbon steel St37 was chosen according to the Russian Standards (Gost) . Its chemical analysis is shown in Table (1).

Preparation of welding piece

- Selection metallic plates, 10 mm
- thick, 60 mm long and 40 mm
- wide .
- making preparation V angle of 15°.
- The operation is repeated on the remaining pieces to make V angles of (30° and 45°)
- Another piece of same dimension , but of U-shape (with the radius 4mm) is made.

Welding Process

Welding is done by electric arc (MIG) on the piece. The conditions for the process are indicated in Table(2) .

The Input heat quantity is calculated by the following equation[1]:

$$Heat \quad Input \quad = \frac{543 \times I \times V \times 60}{S}$$

After the welding process, the welded pieces were tested by X-ray radiography. Faulty pieces were excluded. Pieces without faults were prepared in the following manner :

1-Grinding the specimens by sandpapers of grades 220,400,800, and 1100 granule/cm^2 (mesh)

2- Polishing process by using of polishing cloth with Aluminum oxide (Al_2O_3, having particles of 5 micron) as a polishing assistant .

3- Etching by Nital solution , which is composed of (98% Methyl alcohol + 2% Nitric acid)

4- Examination of the microstructure by a light microscope of 400X magnification.

5- Photographing the microstructure .

Fig.(1) shows the microstructure for base metal, Heat affected zone (Haz) and welded zone.

Welding Wire

The welding wire (AWS ER705-6) is used with 1.2mm diameter in which the chemical composition is shown in Table(3).

Theoretical Consideration

Theoretically the welding process can be considered either using a thermal or a mechanical analysis. Thermal stresses induced during a welding process are obtained from the temperature distributions determined by the thermal model. The stresses from each temperature increment are added to the nodal point location to determine the updated behavior of the model before the next temperature increment. There are two district methods: sequential and direct in a coupled-field analysis. Which procedure for a coupled- field analysis will be used depends on which fields are being coupled. The sequential method involves two or more sequential analyses that belong to a different filed. Adversely, the direct method usually involves just on analysis that uses a coupled-field element type containing all necessary degrees of freedom. In this work, the process of welding is simulated by the finite element method. The welding process computation can be done to get thermal and mechanical analysis, the temperatures are determined as a function of time in the analysis. Then, the mechanical analysis employs the previous results to get displacements at nodes and stresses at integration points. Since the thermal field has a strong influence on the stress field with little inverse influence. Moreover, a three dimensional finite element analysis is the optimum method of ascertaining the thermal cycle of welding. Therefore, in this paper, the welding process is simulated using a direct coupled three dimensional thermo-mechanical finite element formulation based on the ANSYS code[7]. For both the thermal and mechanical analysis, temperature- dependent thermo- physical and mechanical properties of materials are incorporated. The temperature dependent thermal material properties for the plates, heat affected zone and the filler weld material were assumed to be the same. The plasticity material model used was von Misses rate-independent kinematic bilinear hardening. Table(4) illustrated the material properties[6]. Fig.(2) shown the element type SOLID98 which has coupled degree of freedom was used for the thermal- mechanical analysis in the present work. The ANSYS steps can be demonstrated in the following program which is done in ANSYS to make the butt welding analysis[8].

```
/view,1,1,1,1
/prep7
Et,1,solid98
mp,dens,1,7880
mp,kxx,1,60
mp,c,1,480
mp,ex,1,210e9
mp,nuxy,1,0.3
mp,alpx,1,1.15e-5
TB,bkin,1
tbtemp,80
tbdata,1,380e6,210e9*0.85
mptemp,1,0,100,200,400,600,800,100
0,1200,1400,1550
mpdata,c,2,1,480,500,520,650,750,10
00,1200,1400,1600,1700
mpdata,kxx,2,1,60,50,45,38,30,25,26,
28,37,37
mpdata,dens,2,1,7880,7880,7800,776
0,7600,7520,7390,7300,7250,7180
mpdata,alpx,2,1,1.15e-5,1.2e-5,1.3e-
5,1.42e-5,1.45e-5,1.45e-5,1.45e-
5,1.45e-5,1.45e-5,1.45e-5
mpdata,Ex,2,1,210e9,200e9,200e9,17
0e9,80e9,35e9,20e9,15e9,10e9,10e9
mpdata,nuxy,2,1,0.3,0.3,0.3,0.3,0.3,0.
3,0.3,0.3,0.3,0.3
x1=0.003
y1=0.002
theta=7.5
*afun,deg
xx=(0.01-y1)*tan(theta)
k,1,0,0
k,2,0.06,0
k,3,0.06,y1
k,4,0.06-xx,0.01
k,5,0,0.01
k,6,0.06+x1,0
k,7,0.06+x1,y1
k,8,0.06+x1+xx,0.01
k,9,0.06+x1+0.06,0.01
k,10,0.06+x1+0.06,0
k,12,0.06+(x1/2),0.0125
a,1,2,3,4,5
a,6,7,8,9,10
voffst,1,0.04
voffst,2,-0.04
csys,1
spline,4,12,8
l,2,6
a,2,6,7,8,12,4,3
voffst,15,0.04
vglue,all
type,1:mat,1:real,1
vmesh,1,2,1
type,1:mat,2:real,1
vmesh,4
nummrg,all
finish
/solu
antype,trans
asel,s,area,,8
asel,a,,,13
nsla,s
d,all,all
allsel
asel,s,,,25
asel,a,,,26
nsla,s
tunif,25
q=45812910
sf,all,hflux,q
allsel
time,0.5       ! time  seconds
deltim,0.5
kbc,1
autots,on
timint,on
tintp
outres,all,all
cnvtol,heat,500,0.1
solve
```

finish

In fig.(3) are shown the modeling of welding process of a butt weld joint of two St-37 steel plates .

Results and Discussion

By observing the photos of the microstructure and calculated heat quantity as shown in Table (2), it is found that with decreasing preparation angle of the welded plates, the heat quantity increases, quantity of welding metal decreases, welding region possesses better quantities, greater heat transfer to adjoining region (which is effected directly by heat), while it can be shown that the heat quantity is equal with 30° V and 40° V due to the same input parameters.

Increasing of heat quantity contributes at growth of granules' volume with high ductility due to slow cooling of the metal during welding as well as weak mechanical properties (resistance to tension and hardness). Therefore, it is preferred that the welding angle be 45° for homogenous heat distribution to it.

Fig.(1) shows the variance of the particles of the weld region for the different geometry of 15° single V, 30° single V, 45° single V and U single shapes as follows:-

It is evidenced from the figure that the microstructure becomes finer with the increase of the geometric forms' value of the welding region for specimens15°, 30° , 45° respectively.

Fig.(5) shows the stress distribution and temperature distribution in the weld region while Fig.(6) shows the stress distribution and temperature distribution in the whole welded plates. Weldability differs from one metal or alloy to another. It depends on its material properties (Table-4-), chemical composition and the method of welding. To insure good weld for the metal, the latter should be a good heat conductor, of little shrinkage and of small longitudinal expansion index. Poor heat conductivity leads to heat concentration in small part and non equality of the temperature of the whole work. The more intense are the generated internal stresses, the greater would be the longitudinal expansion index and its shrinkage is greater. Fig.(4) is a schematic drawing of a cross-section of the weld and its adjoining region in which is manifested the thermal influence of the weld. The weld structure consists of region "a" of large sized cast structure which is a characteristic of the alloyed metal. This region is followed by the region of excess heating "b"; this is due to influence of high temperature excess heating greatly lowers the plasticity and shock resistance. It forms in the region "c" which is heated to a little higher temperature than line GS (i.e. line between two regions in fig.(4)) upon air cooling. Gradually, this region shifts to region "d" which is heated to a temperature below line GS. Upon slow cooling, this leads to incomplete plasticizing. In region "e" the temperature of the heated metal does not reach to the region of phase recrystalization of the steel .Thus, the structure of the base metal in it is not influenced by the heating due to welding. So, the weld creates different structure in the adjoining its regions causing great degradation of its properties. Shifts in the structures of regions “a”, “b” and “c” help at generation of internal stresses in it.

Evidently good welding quality would be better as the region adjacent to the seams of the weld is smaller. Weldability of low carbon steel down to 0.2% is very good. By increasing the carbon percentage, heat conductivity of steel decreases and the internal stresses in it are increased.

Conclusions

1. Weld angle depends on the thickness of the metal to be welded.
2. When the welding angle is increased, the stuffing material and it is properties, have an influence on the properties of welding region.
3. Heat quantity depends on the variables of welding process (voltage, current , ..etc)
4. From the results of the microscopic structure it is evident that the geometric shape has an important role in the welding process. That is when the geometric value (15°V, 30°V,45°V and U shape) of the welding region gets bigger, the faults get less due to increase of heat quantity in the welding region.
5. The work presents the finite element model for numerical simulation of welding stresses in low carbon steel St-37 butt welding. The welding simulation was considered as a direct coupled thermo- mechanical analysis.

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Table (1) The Chemical Properties of the used Metal St 37

Wt% of element	C	Si	Mn	Cr	Mo	Cu	Co	V	W	Ai	Ni	P	S
Actual value %	0.2	0.009	0.65	0.011	0.004	0.041	0.004	0.0009	0.003	0.001	0.012	0.09	0.05
Standard value %	0.18-0.23	0.01	0.3-0.6	-	-	-	-	-	-	-	-	0.04	0.05

Table (2) Conditions of the Welding process

	Current I (Amp)	Voltage V	Welding speed (S) m/min	No. of passes	Metal thickness mm	Input heat quantity (Joule)
15° V angle	286	29.5	6	3	10	$4.6x10^7$
30° V angle	296	30.5	8.5	3	10	$3.5x10^7$
45° V angle	296	30.5	8.5	4	10	$3.5x10^7$
U shape	296	30.5	8	5	10	$3.7x10^7$

Table (3) The Chemical composition of wire welding

element	C	Si	Mn	P	S	al	Ni	Cr	Cu	Mo
Wt%	0.068	0.763	1.41	0.02	0.014	0.002	0.041	0.026	0.026	0.002

Table (4) Material Properties[6]

Temperature (°C)	Specific Heat (J/kg°C)	Conductivity (W/m°C)	Density (kg/m^3)	Yield Stress (MPa)	Thermal Expansion Coefficient (10-5/°C)	Young's modulus (GPa)	Poisson's
0	480	60	7880	380	1.15	210	0.3
100	500	50	7880	340	1.2	200	0.3
200	520	45	7880	315	1.3	200	0.3
400	650	38	7760	230	1.42	170	0.3
600	750	30	7600	110	1.45	80	0.3
800	1000	25	7520	30	1.45	35	0.3
1000	1200	26	7390	25	1.45	20	0.3
1200	1400	28	7300	20	1.45	15	0.3
1400	1600	37	7250	18	1.45	10	0.3
1550	1700	37	7180	15	1.45	10	0.3

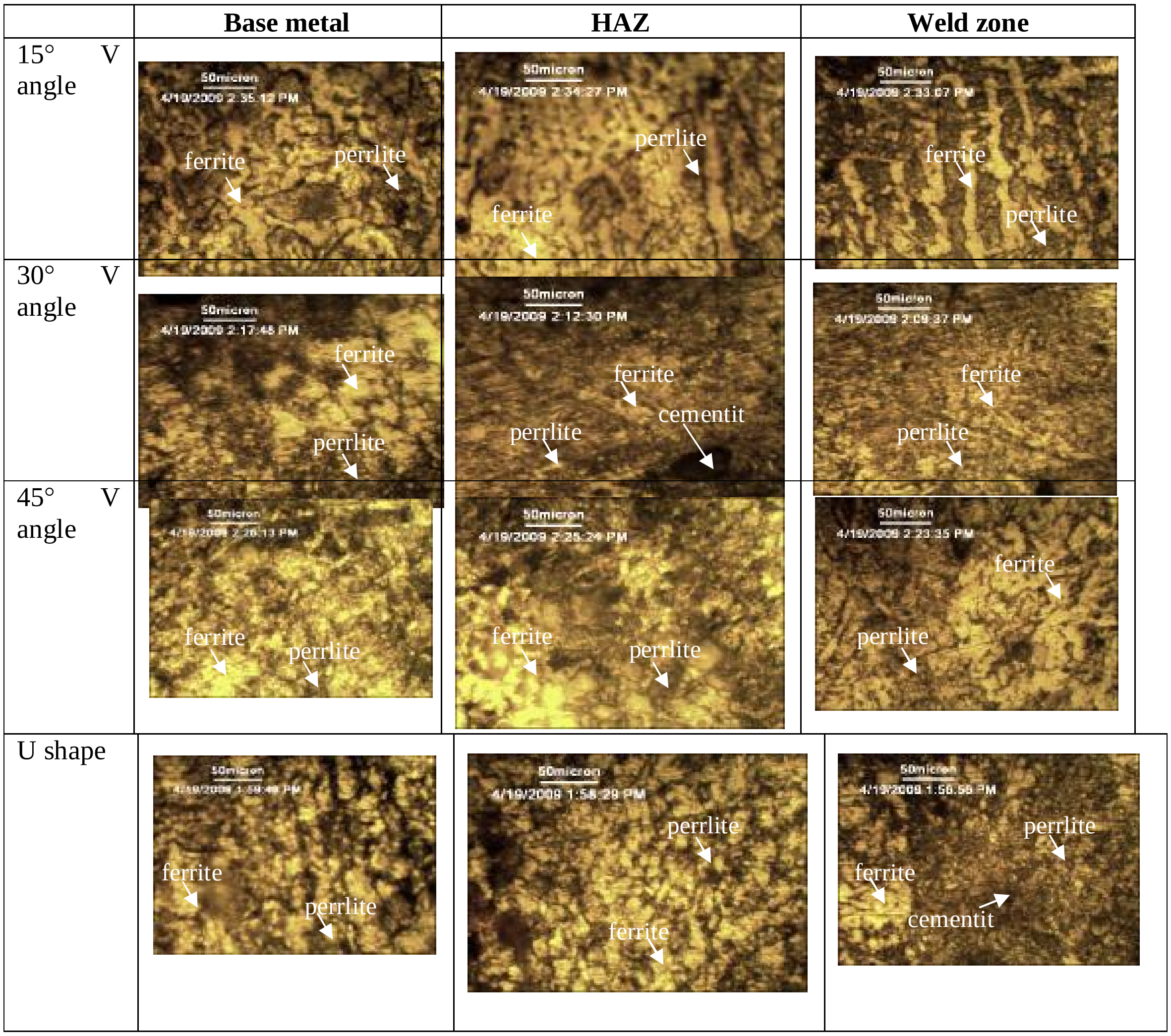


Figure (1) Show the microstructure of butt welding, it is clear from these plates there is no porosity according to x-ray radiography and the phases in these microstructure are ferrite -yellow places- and perrlite – black places- and the darkness places is cementite

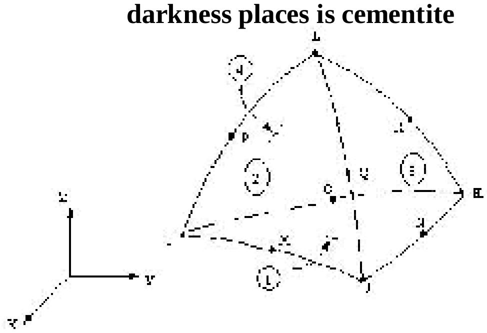


Figure (2) Element type used in the analysis

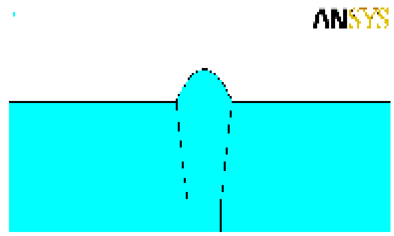
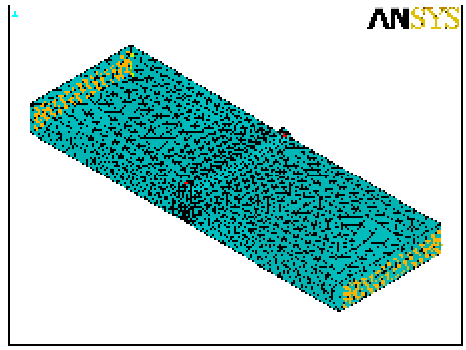
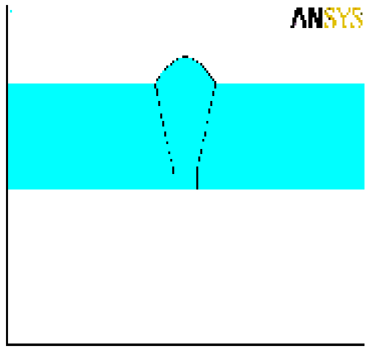
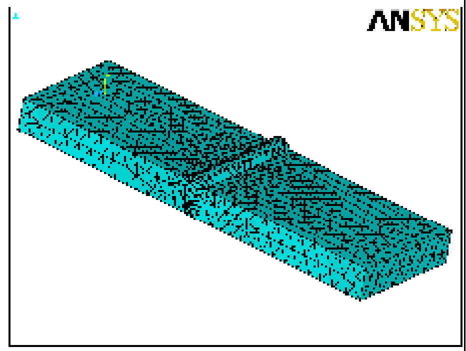
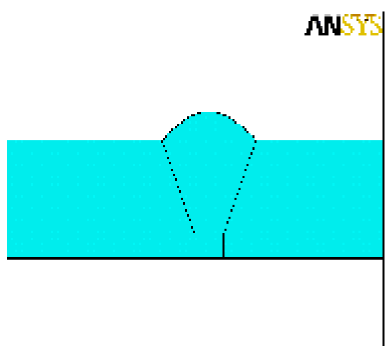
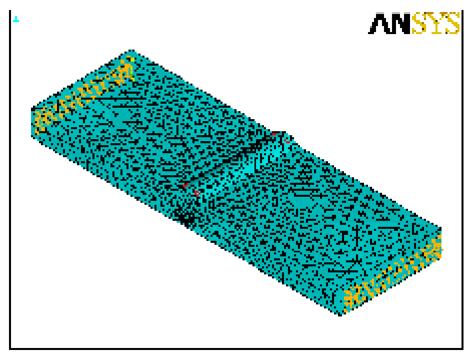
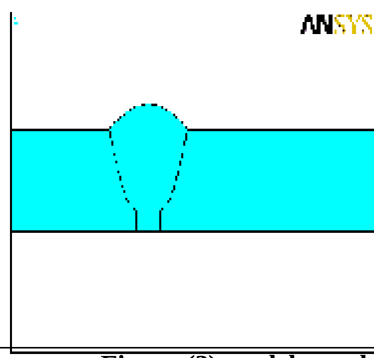
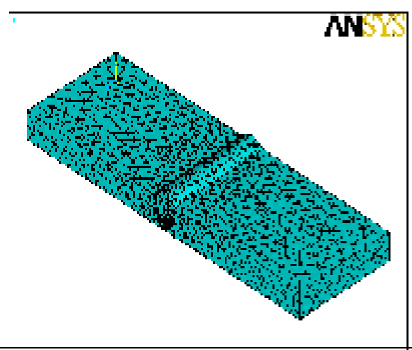
15° V angle		
30° V angle		
45° V angle		
U shape		

Figure (3) models used in the analysis

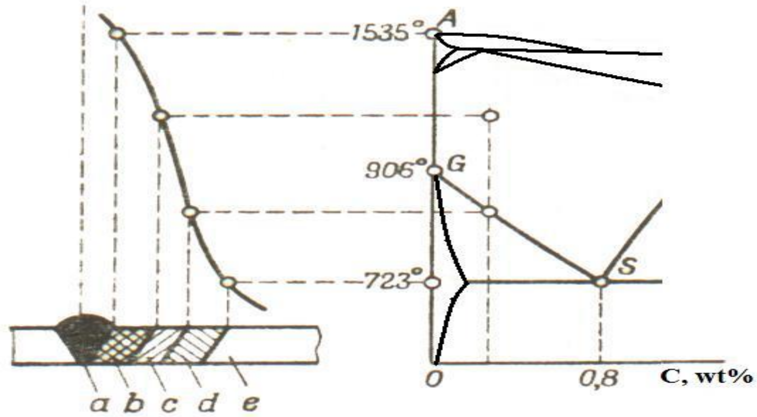
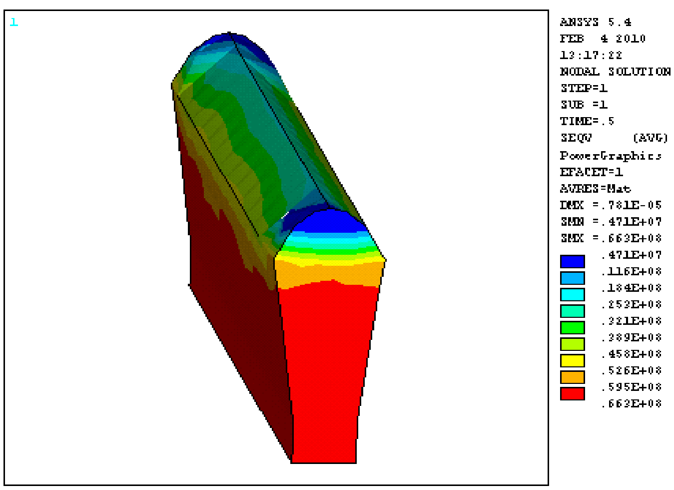
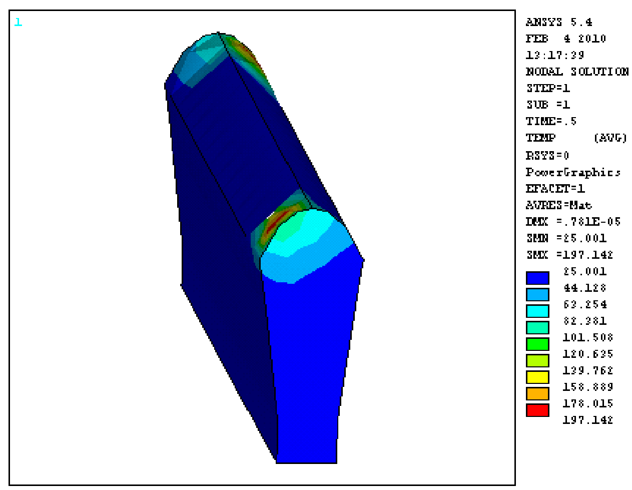


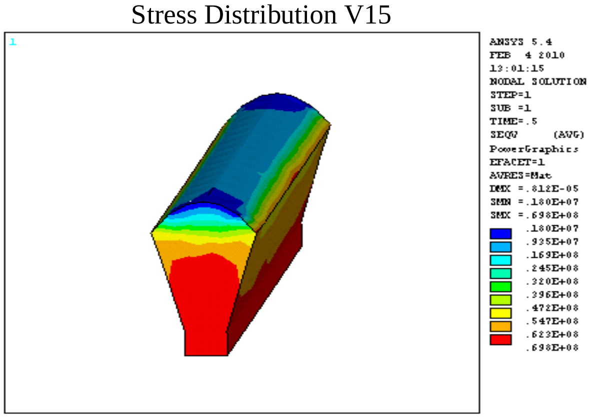
Figure (4) The structure of the welded piece (a- weld zone , b- heat effected zone, c- heated zone (Temp. above the GS line), d- heated zone (Temp. below the GS line) , e- base metal)



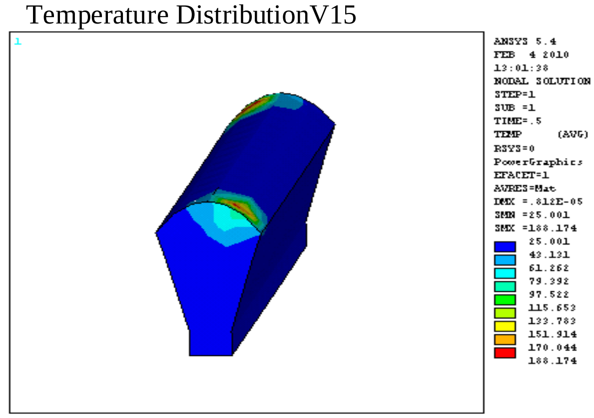
Stress Distribution V15



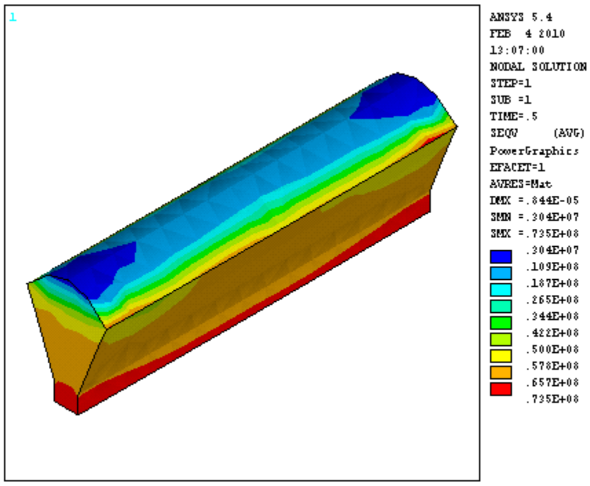
Temperature DistributionV15



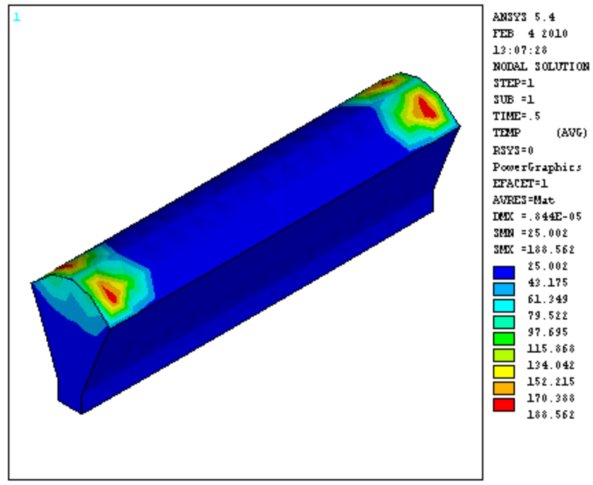
Stress Distribution V30



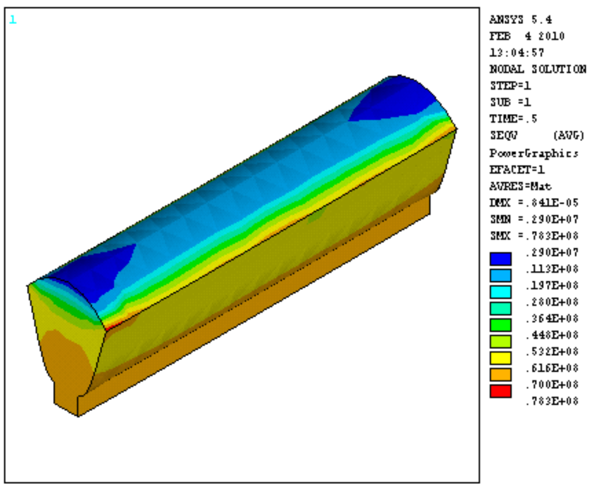
Temperature DistributionV30



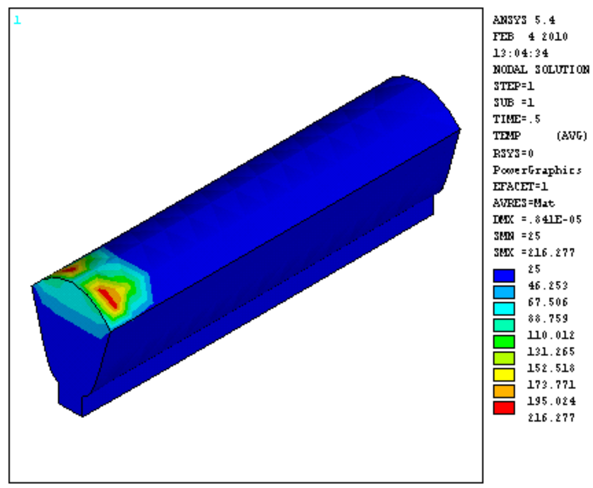
Stress Distribution V45



Temperature DistributionV45

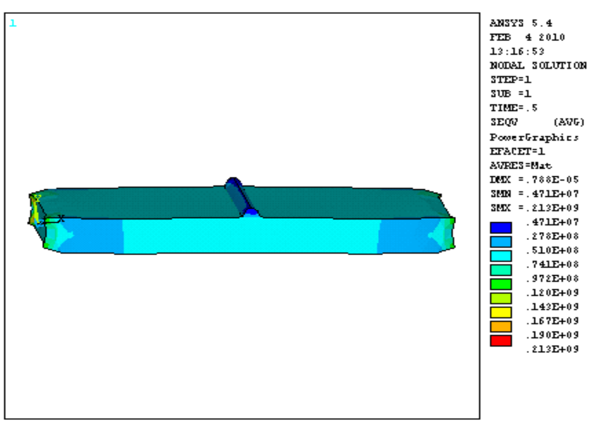


Stress Distribution U shape

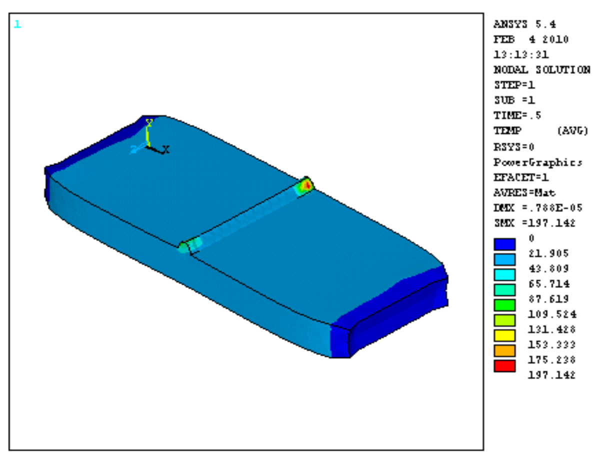


Temperature Distribution U shape

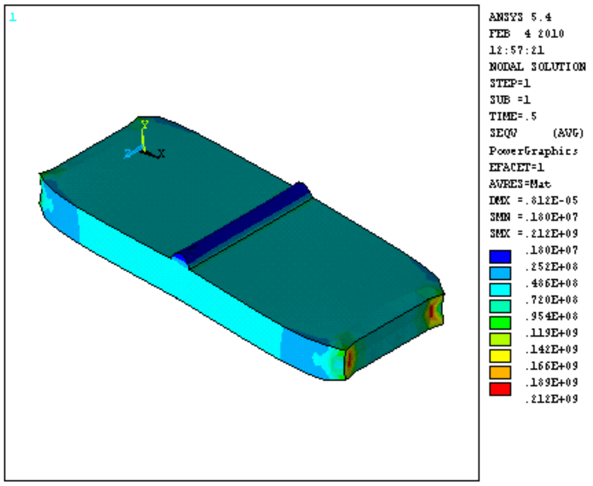
Figure (5) Show the stress distribution and temperature distribution in welding region



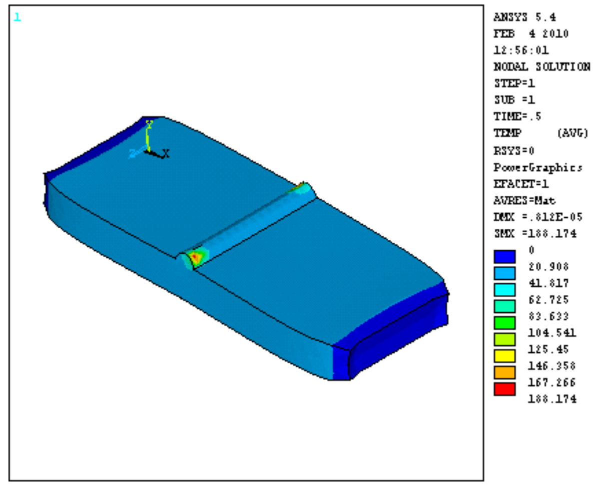
Stress Distribution V15



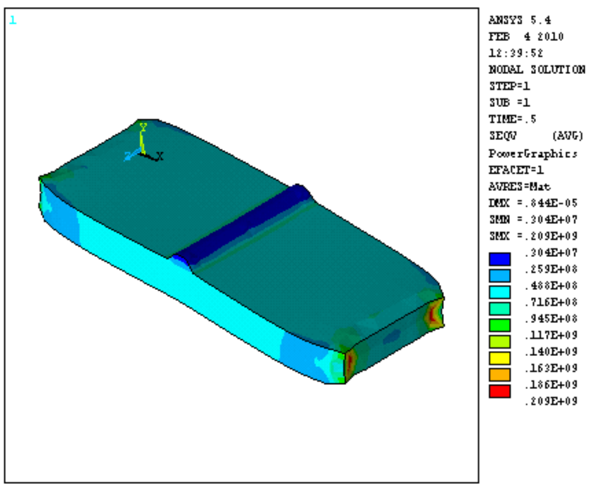
Temperature DistributionV15



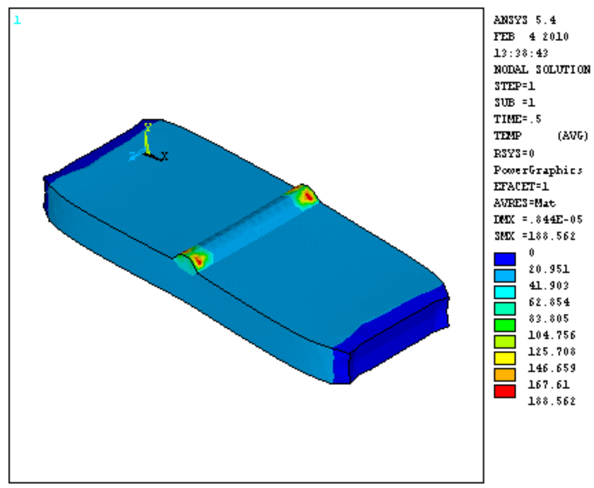
Stress Distribution V30



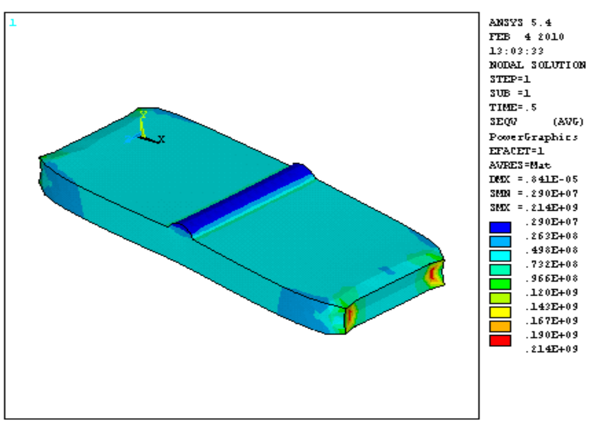
Temperature DistributionV30



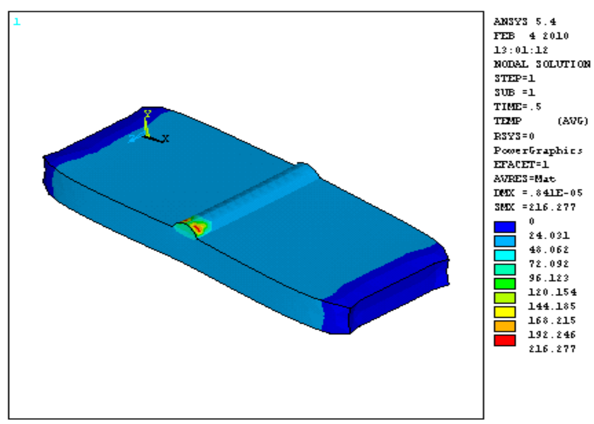
Stress Distribution V45



Temperature DistributionV45



Stress Distribution U shape



Temperature Distribution U shape

Figure (6) Show the stress distribution and temperature distribution in welded plates