TRANSIENT HEAT TRANSFER ANALYSIS FOR OPTIMUM TEMPARATURE DISTRIBUTION TO REDUCE THERMAL STRESSES*

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ABSTRACT

This project investigated the thermal stresses of aluminum plate welded by gas tungsten arc (GTA) in boilers and pressure vessels. The heat of fusion, the size and distribution of heat source, the travel speed, the heat conduction in the welding direction and the surface heat loss during welding were considered. Simulation was carried out on a plate made of Aluminum having dimensions 0.05×0.05×0.005 meters. Single pass welding was carried out. Simulation values calculated were taken as input for the analysis in ANSYS software.

A model was generated in ANSYS12.0 (general purpose FEA software) using SOLID 98. A refined mesh is made based on the convergence criteria and the analysis is performed to estimate the thermal stresses. Couple field analysis using structural load of pressure 4N/mm^2 on areas and thermal loads of 2500 kJ is carried out by giving heat flux as the time varying input to estimate the thermal stresses, thermal strain, displacement and temperature gradient variations .The non linear material properties are fed for the heat flow solution to get the thermal stresses. The variation of the temperature gradient with time, and thermal stress are obtained. The variation of these are reported and discussed.

The present analysis is used to calculate thermal gradients thereby reduce thermal stresses for the optimum temperature distribution in aluminum welded joints.

Keywords: *Gas tungsten arc (GTA) welding, Thermal gradient, Thermal stresses, Finite element analysis.*

INTRODUCTION

1.1Modes of Heat Transfer:

Heat transfer which is defined as the transmission of energy from one region to another as a result of temperature gradient takes place by the following three modes:
(i) Conduction (ii) Convection (iii) Radiation.

Heat transmission, in majority of real situations, occurs as a result of combinations of these modes of heat transfer. Example: The water in a boiler shell receives its heat from the fire-bed by conducted, convected and radiated heat from the fire to die shell, conducted heat through the shell and conducted and convected heat from the inner shell wall, to the water. Heat always flows in the direction of lower temperature.

The above three modes are similar in that a temperature differential must exist and the heat exchange is in the direction of decreasing temperature; each method, however, has different controlling laws.

Conduction:

Conduction is the transfer of heat from one part of a substance to another part of the same substance, or from one substance to another in physical contact with ft without appreciable displacement of molecules forming the substance.

In solids, the heat is conducted by the following two mechanisms:

I. By lattice vibration (the faster moving molecules or atoms in the hottest part of a body transfer heat by impacts some of their energy to adjacent molecules.

II. By transport of free electrons (Free electrons provide an energy flux in the direction of decreasing temperature — For metals, especially good electrical conductors, the electronic mechanism is responsible for the major portion of the heat flux except at low temperature).

In case of gases, the mechanism of heat conduction is simple. The kinetic energy of a molecule is a function of temperature. These molecules are in a continuous random motion exchanging energy and momentum. When a molecule from the high temperature region collides with a molecule from the low temperature region, it loses energy by collisions.

In liquids, the mechanism of heat is nearer to that of gases. However, the molecules are more closely spaced and intermolecular forces come into play.

Convection:

Convection is the transfer of heat within a fluid by mixing of one portion of the fluid with another.

• Convection is possible only in a fluid medium and is directly linked with the transport of medium itself.

• Convection constitutes the macro form of the heat transfer since macroscopic particles of a fluid moving in space cause the heat exchange.

• The effectiveness of heat transfer by convection depends largely upon the mixing motion of the fluid.

This mode of heat transfer is met with in situations where energy is transferred as heat to a flowing fluid at any surface over which flow occurs. This mode is basically conduction in a very thin fluid layer at the surface and then mixing caused by the flow. The heat flow depends on the properties of fluid and is independent of the properties of the material of the surface. However, the shape of the surface will influence the flow and hence the heat transfer.

Free or natural convection. Free or natural convection occurs when the fluid circulates by virtue of the natural differences in densities of hot and cold fluids; the denser portions of the fluid move downward because of the greater force of gravity, as compared with the force on the less dense.

Basic Concepts

Forced convection. When the work is done to blow or pump the fluid, it is said to be forced convection.

Radiation:

Radiation is the transfer of heat through space or matter by means other than conduction or convection.

Radiation heat is thought of as electromagnetic waves or quanta (as convenient) an emanation of the same nature as light and radio waves. All bodies radiate heat; so a transfer of heat by radiation occurs because hot body emits more heat than it receives and a cold body receives more heat than it emits. Radiant energy (being electromagnetic radiation) requires no medium for propagation and will pass through vacuum.

The rapidly oscillating molecules of the hot body produce electromagnetic waves in hypothetical medium called ether. These waves are identical with light waves, radio waves and X-rays, differ from them only in wavelength and travel with an approximate velocity of 3 x-10 m/s. These waves carry energy with them and transfer it to the relatively slow-moving molecules of the cold body on which they happen to fall.

The molecular energy of the later increases and results in a rise of its temperature. Heat travelling by radiation is known as radiant heat.

The properties of radiant heat in general, are similar to those of light. Some of the properties

are:

- It does not require the presence of a material medium for its transmission.
- Radiant heat can be reflected from the surfaces and obeys the ordinary laws of reflection.
- It travels with velocity of light.
- Like light, it shows interference, diffraction and polarization etc.
- It follows the law of inverse square.

The wavelength of heat radiations is longer than that of light waves, hence they are invisible

to the eye.

1.2 Types of Thermal Analysis :

ANSYS supports two types of thermal analysis:

1. A steady-state thermal analysis determines the temperature distribution and other thermal quantities under steady-state loading conditions. A steady-state loading condition is a situation where heat storage effects varying over a period of time can be ignored.
2. A transient thermal analysis determines the temperature distribution and other thermal quantities under conditions that vary over a period of time.

Steady-State Thermal Analysis:

The ANSYS Multi physics, ANSYS Mechanical, ANSYS FLOTRAN, and ANSYS Professional products support steady-state thermal analysis. A steady-state thermal analysis calculates the effects of steady thermal loads on a system or component. Engineer/analysts often perform a steady-state analysis before performing a transient thermal analysis, to help establish initial conditions. A steady-state analysis also can be the last step of a transient thermal analysis, performed after all transient effects have diminished.

By the use of steady-state thermal analysis to determine temperatures, thermal gradients, heat flow rates, and heat fluxes in an object that are caused by thermal loads that do not vary over time. Such loads include the following:

1. Convections
2. Radiation
3. Heat flow rates
4. Heat fluxes (heat flow per unit area)
5. Heat generation rates (heat flow per unit volume)
6. Constant temperature boundaries

A steady-state thermal analysis may be either linear, with constant material properties; or nonlinear, with material properties that depend on temperature. The thermal properties of most material do vary with temperature, so the analysis usually is nonlinear. Including radiation effects also makes the analysis nonlinear

FINITE ELEMENT MODEL

SOLID98 Geometry:

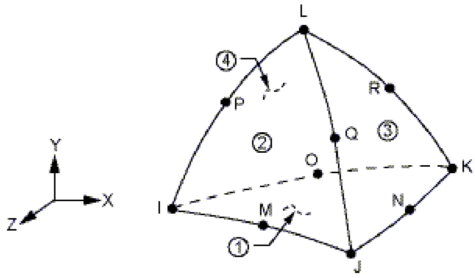

Fig.3. SOLID98 Element Geometry

SOLID98 is a 10-node tetrahedral version of the 8-node solid5 element. The element has a quadratic displacement behaviour and is well suited to model irregular meshes (such as produced from various cad/cam systems). When used in structural and piezoelectric analyses, solid98 has large deflection and stress stiffening capabilities. The element is defined by ten nodes with up to six degrees of freedom at each node. (see key pt(1)). The 3-D magnetic, thermal, electric, piezoelectric, and structural field capability is similar to that described for solid5.

Material Properties

Aluminium:

Thermal conductivity = 155(W/m-k)
Specific Heat = 915(J/kg-k)
Density = 2750 (kg/m^3)

RESULTS

Table.1 The minimum and maximum temperature gradient of different welded joints in aluminium material.

S.NO	Type Of Joints	Min.Temp Gradient	Max.Temp Gradient
1	Lap	17.197	840.669
2	T-Joint	-374.902	489.687
3	Corner	-722.627	1170.2

Table.2 The thermal stresses induced in different welded joints

S.NO	Type Of Joints	Thermal Stresses
1	Lap	50.25
2	T-Joint	45.54
3	Corner	33.53

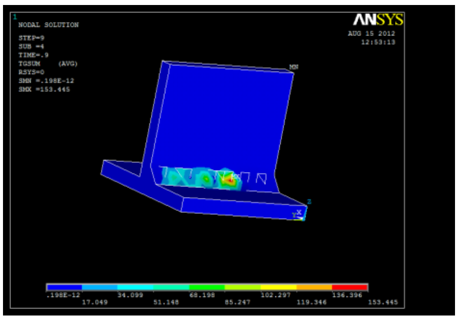

Fig.7 The Temperature Gradient Range of T-Joint under structural and thermal loads

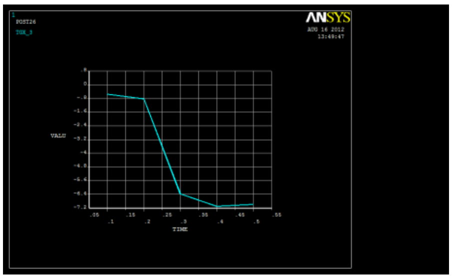

Fig.8 The variation of Temperature gradient of node 56 w.r.t time

The above figure shows the variation of temperature gradient with respect to time for node (56).At the time 0.1sec's the temperature gradient is minimum and at the time 0.5 sec's the temperature gradient is maximum. Regarding this minimum and maximum values of temperature gradients are varying with time.

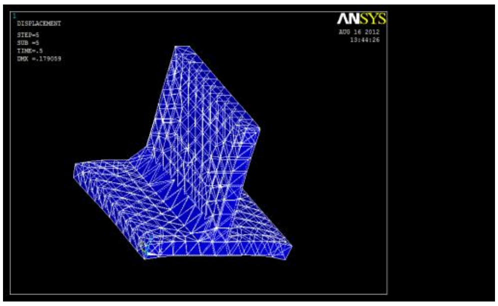

Fig.9 The Displacement of T-Joint under structural and thermal loads

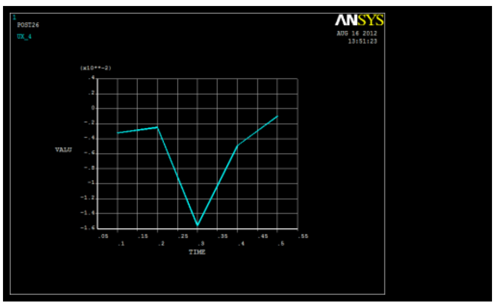

Fig.10 The variation of Displacement of node 56 w.r.t time

The above figure shows the variation of displacement with respect to time for node (56).At the time 0.1sec's the displacement is minimum and at the time 0.5 sec's the displacement is maximum. Regarding this minimum and maximum values of displacement is varying with time.

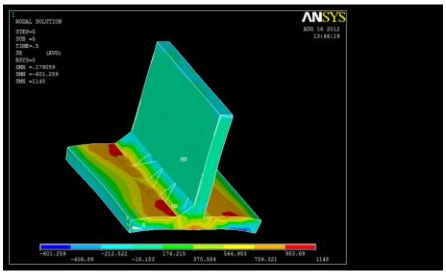

Fig.11 The Stresses of T-Joint under structural and thermal loads

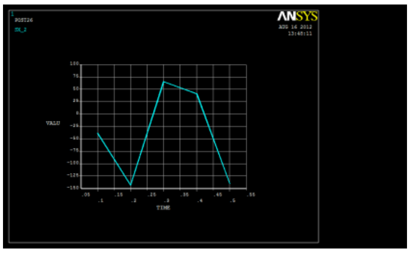

Fig.12 The variation of Stresses of node 56 w.r.t time

The above figure shows the variation of stresses with respect to time for node (56).At the time 0.1sec's the stresses are minimum and at the time 0.5 sec's the stresses are maximum. Regarding this minimum and maximum values of stresses are varying with time.

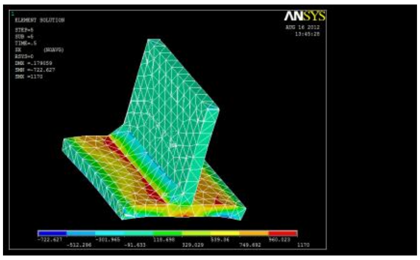

Fig.13 The Thermal Strain of T-Joint under structural and thermal loads

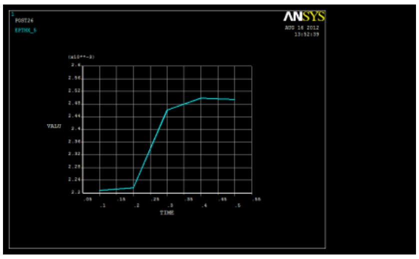

Fig.14 The variation of Thermal Strain of load 56 w.r.t time

The above figure shows the variation of thermal strain with respect to time for node (56).At the time 0.1sec's the thermal strain is minimum and at the time 0.5 sec's the thermal strain is maximum. Regarding this minimum and maximum values of thermal strain is varying with time.

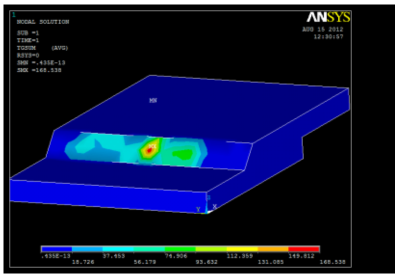

Fig.15 The Temperature Gradient Range of Lap Joint under structural and thermal loads

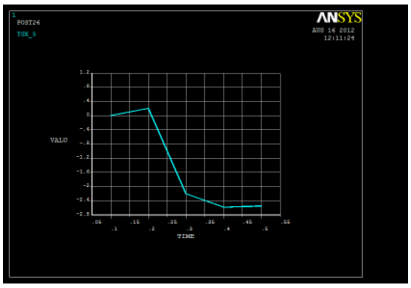

Fig. 16 The variation of Temperature gradient of node 97 w.r.t time

The above figure shows the variation of temperature gradient with respect to time for node (97).At the time 0.1sec's the temperature gradient is minimum and at the time 0.5 sec's the temperature gradient is maximum. Regarding this minimum and maximum values of temperature gradients are varying with time.

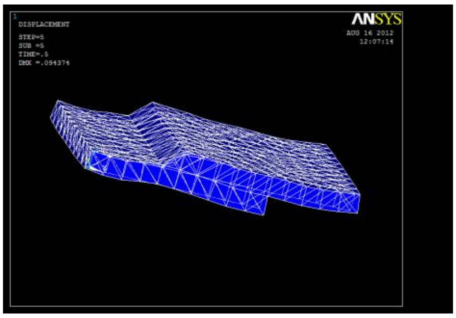

Fig.17 The Displacement of Lap Joint under structural and thermal loads

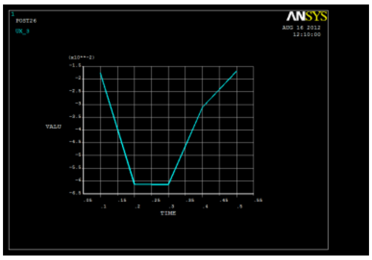

Fig.18 The variation of Displacement of node 97 w.r.t time

The above figure shows the variation of displacement with respect to time for node (97).At the time 0.1sec's the displacement is minimum and at the time 0.5 sec's the displacement is maximum. Regarding this minimum and maximum values of displacement is varying with time.

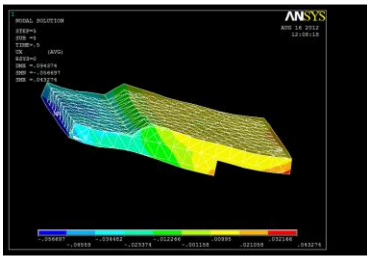

Fig.19 The Stresses of Lap Joint under structural and thermal loads

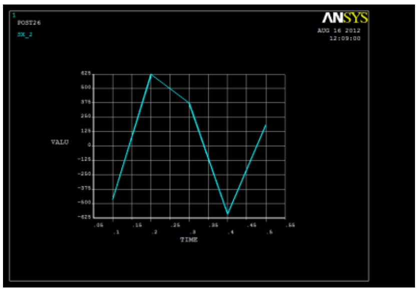

Fig.20 The variation of Stresses of node 97 w.r.t time

The above figure shows the variation of stresses with respect to time for node (97).At the time 0.1sec's the stresses are minimum and at the time 0.5 sec's the stresses are maximum. Regarding this minimum and maximum values of stresses are varying with time.

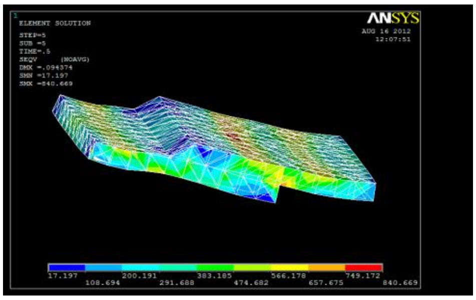

Fig.21 The Stresses of Element solution of Lap Joint under structural and thermal loads

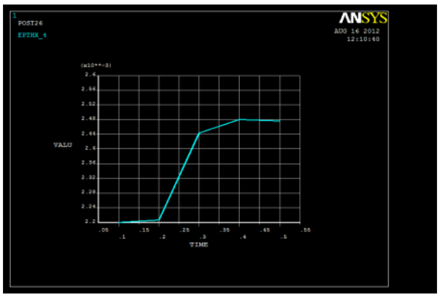

Fig.22 The variation of Thermal Strain of node 97 w.r.t time

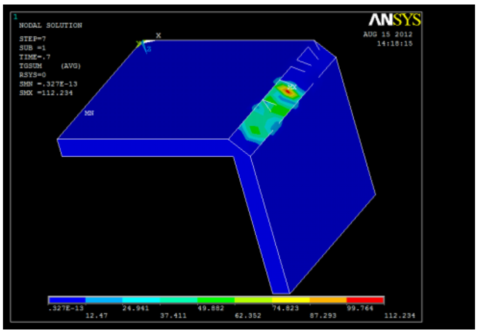

Fig.23 The Temperature Gradient Range of Corner Joint under structural and thermal loads

The above figure shows the variation of thermal strain with respect to time for node (97).At the time 0.1sec's the thermal strain is minimum and at the time 0.5 sec's the thermal strain is maximum. Regarding this minimum and maximum values of thermal strain is varying with time.

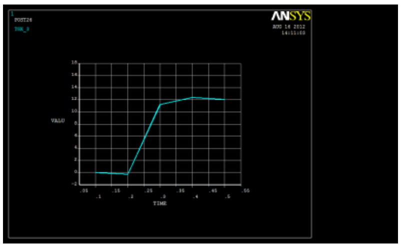

Fig.24 The variation of Temperature gradient of node 1324 w.r.t time

The above figure shows the variation of temperature gradient with respect to time for node (1324).At the time 0.1sec's the temperature gradient is minimum and at the time 0.5 sec's the temperature gradient is maximum. Regarding this minimum and maximum values of temperature gradients are varying with time.

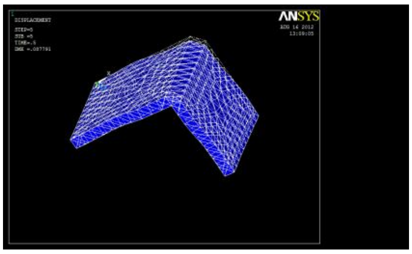

Fig.25 The Displacement of Corner Joint under structural and thermal loads

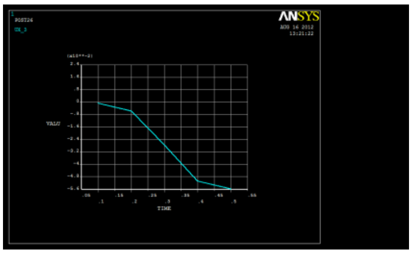

Fig.26 The variation of Displacement of node 1324 w.r.t time

The above figure shows the variation of displacement with respect to time for node (1324).At the time 0.1sec's the displacement is minimum and at the time 0.5 sec's the displacement is maximum. Regarding this minimum and maximum values of displacement is varying with time.

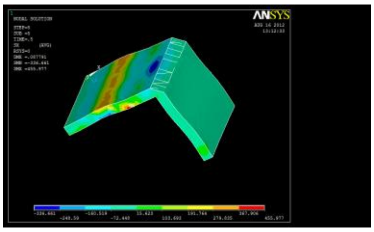

Fig.27 The Stresses of Corner Joint under structural and thermal loads

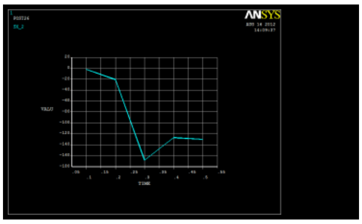

Fig.28 The variation of Stresses of node1324 w.r.t time

The above figure shows the variation of stresses with respect to time for node (1324).At the time 0.1sec's the stresses are minimum and at the time 0.5 sec's the stresses are maximum. Regarding this minimum and maximum values of stresses are varying with time.

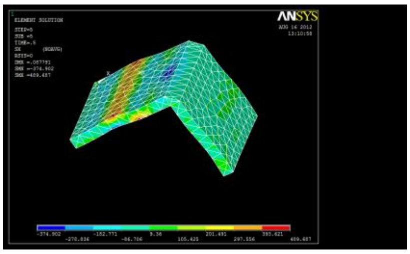

Fig.29 The Stresses of Element solution of Corner Joint under structural and thermal loads

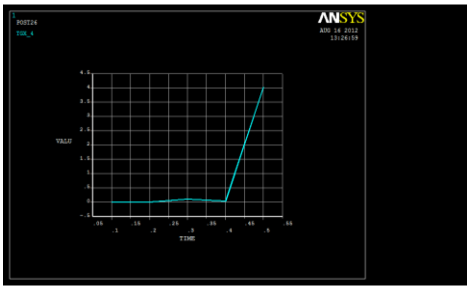

Fig.30 The variation of Thermal Strain of node 1324 w.r.t time

The above figure shows the variation of thermal strain with respect to time for node (1324).At the time 0.1sec's the thermal strain is minimum and at the time 0.5 sec's the thermal strain is maximum. Regarding this minimum and maximum values of thermal strain is varying with time.

The Variation of Thermal Stresses In Different Welded Joints:

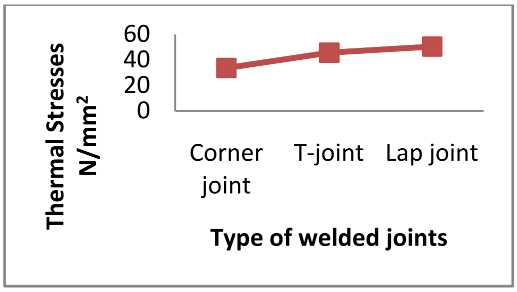

Fig.31 The Variation of Thermal Stresses In Different Welded Joints

The graph shows the variation thermal stresses with different types of welded joints of aluminium material. The uniform temperature of all the welded joints are same (200^{0}C) and also the heat (2500 kJ) is same. But the result of thermal stresses are different.

CONCLUSION

Couple analysis using structural load of pressure 4N/mm^2 on areas and thermal loads was carried out by giving heat flux as the time varying input to estimate the thermal stresses, thermal strain, displacement and temperature gradient variations .The non linear material properties are fed for the heat flow solution to get the thermal stresses. The variation of the temperature gradient with time, and thermal stress are obtained.

The thermal stresses can be reduced by heating the plates to pre heat temperature. This can also be reduced by selecting the material of lower young's modulus. In Gas Tungsten Arc Welding, atmospheric air with forced convection can transfer the heat generated so that temperature gradient is less there by thermal stresses can be reduced.

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