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Simulation of Welding for Dissimilar Metals using Abaqus

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Abstract— Welding is the widely used fabrication process for the development of structural components. During the course of welding, high residual stresses often occur. This causes the problem in nuclear power plant components especially where the danger of stress corrosion cracking is predominant. This paper describes the simulation of welding on dissimilar metals, Copper and stainless steel. a welding simulation is developed for dissimilar metals followed by a model for TIG welding. In this work a Finite element model for dissimilar welding of stainless steel & Copper is done. A simple 3D Sequential thermal analysis is done using ABAQUS software. Temperature dependent thermal properties were used. A transient heat load is given representing welding load at the weld joint is used. The outcome of the heat input is nodal temperatures at nodes, heat flux and residual stress. First, two Stainless Steel plates were joined; next two Copper plates were joined and finally a Stainless Steel plate was joined to a Copper plate by welding. At the weld joint parameters such as temperature and residual stresses were obtained and analyzed. This study will provide an insight to the designer for obtaining feasibility of providing such a weld and for further fatigue life studies.

Key words: Elect TIG Welding, ABAQUS, Stainless steel copper, nodal temperatures and Heat Flux

I. INTRODUCTION

Welding is one of several fusion processes for joining metals. By applying intense heat, metal at the joint between two parts is melted and caused to intermix - directly, or more commonly, with an intermediate molten filler metal. Upon cooling and solidification, a metallurgical bond is created. Since the joining is an intermixture of metals, the final weldment potentially has the same strength properties as the metal of the parts. This is in sharp contrast to non-fusion processes of joining (i.e. soldering, brazing etc.) in which the mechanical and physical properties of the base materials cannot be duplicated at the joint. Copper alloys are typically used in high temperature applications. The austenitic stainless steels are corrosion and oxidation resistant due to the presence of chromium that forms a self-healing protective film on the surface of the steel. They also have very good toughness at extremely low temperatures so are used extensively in cryogenic applications. They can be hardened and their strength increased by cold working but not by heat treatment. The dissimilar metals joining of stainless steel and copper are having some applications in nuclear industry, chemical and automobile sectors. The joining process poses challenges in the weld process due to the complex melt pool development owing to the difference in the material properties like melting point, thermal conductivity and others. The joining processes like arc welding, brazing, laser beam welding and electron beam welding are attempted for the manufacture of copper and steel joints with different requirements. Simulation of dissimilar joining process gives the knowledge of the various states of the material during the process with respect to the temperature field, residual stress and deformations.

II. TIG WELDING - PRINCIPLE OF TIG WELDING

Gas Tungsten arc welding, also known as tungsten inert gas welding is an arc welding process that uses a non-consumable tungsten electrode to produce the weld. The weld area is protected from atmospheric contamination by a shielding gas and a filler metal is normally used. The equipment required for the gas tungsten arc welding operation includes a welding torch utilizing a non-consumable electrode, a constant current welding power supply, and a shielding source. Gas tungsten arc welding generally has two types of polarity in power supply. They are DCEN and DCEP. The preferred polarity of the GTAW system depends largely on the type of the metal being welded. Direct current with a negatively charged electrode is often employed while welding steels, Nickel, Titanium and other metals. It can also be used in automatic. GTAW of aluminum or magnesium when helium is used as shielding gas direct current with a positively charged electrode is less common, and is used primarily for shallow welds since less heat is generated in the base material.

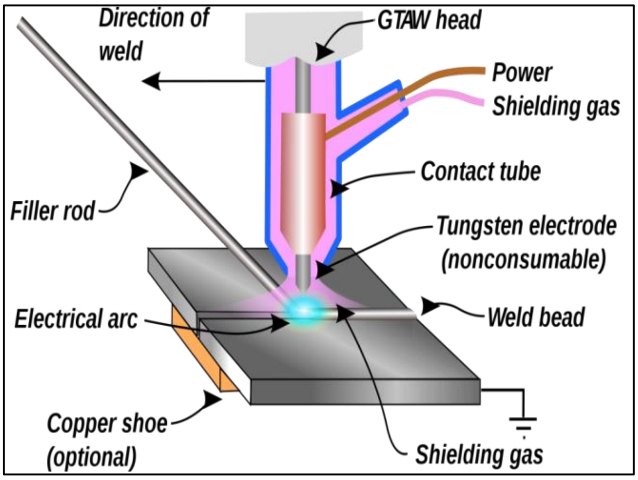

Fig. 1: Tig Welding process

The electrode used in GTAW is made of tungsten or tungsten alloy, because tungsten has the highest melting temperature and electrode is not consumed during the welding, though some erosion can occur. The diameter of the electrode can vary between 0.5 and 6.4 millimeters and their length can range from 75 to 610 millimeters. Filler metals are also used in nearly all applications of GTAW, the major exception being the welding of thin materials. Filler materials are available with different diameters and are made of variety of materials.

AWS Classification	Tungsten, min. percent	Thoria, percent	Zirconia, percent	Total other elements ma. present
EWP	99.5	-	-	0.5
EWTh-1	98.5	0.8 to 1.2	-	0.5
EWTh-2	97.5	1.7 to 2.2	-	0.5
EWZr	99.2	-	0.15 to 0.40	0.5

Table 1: Chemical composition of Tungsten electrodes as per AWS Specification

The current carrying capacity depends on the type of polarity. The typical current ranges for different polarities are tabulated below.

Electrode dia. (mm)	DCEN	DCEP
0.5	5-20	
1.0	15-80	
105	70-150	10-20
2.4	150-250	15-30
3.2	250-400	25-40
4.0	400-500	40-55
4.8	500-750	55-80
6.4	750-1000	80-125

Table 2: Current ranges for pure thoriated tungsten electrode

Shielding gases are necessary in GTAW to protect the welding area from atmospheric gases such as nitrogen and oxygen, which can cause fusion defects, porosity and weld metal embrittlement if they come in contact with the electrode, the arc, or the welding metal. The selection of a shielding gas depends on several factors, including the type of material being welded, joint design etc.

Argon is the most commonly used shielding gas for GTAW. Argon generally provides an arc which operates more smoothly and quietly, is handled more easily. The use of argon results in high weld quality and good appearance. Another common shielding gas, helium, is most often used to increase the weld penetration in a joint, to increase the welding speed, and to weld metals with high heat conductivity, such as copper and aluminum. Argon-hydrogen mixture is used for some grades of stainless steel and nickel alloys.

Welding dissimilar metals often introduces new difficulties to GTAW welding, because most materials do not easily fuse to form a strong bond. However, welds of dissimilar materials have numerous applications in manufacturing. A compatible filler metal is chosen to help form the bond, and this filler metal can be the same as one of the base materials or a different metal.

III. FEA SOFTWARE – ABAQUS

ABAQUS/CAE or "Complete ABAQUS environment. It is a software application used for both the modeling and analysis of mechanical components and assemblies and visualizing the finite element analysis result. A subset of ABAQUS/CAE including only the post-processing module can be launched independently in the ABAQUS/ viewer product. ABAQUS was initially designed to address non-linear physical behavior. As a result, the package has an extensive range of mathematical models such as elastomeric material capabilities.

Every complete finite element analysis consists of three separate stages:

1) Pre-processing or modeling: This stage involves creating an input file which contains an engineer's design for a finite element analyzer.
2) Processing or finite element analysis: This stage produces an output visual file.
3) Post-processing or generating report, image, animation, etc. from the output file. This stage is a visual stage.

Welding of copper and stainless steel is a complex procedure and involves critical parameters to be considered. The input parameters are obtained from the experimental procedure. Residual stresses are introduced in the metals and which may lead to cause a metal part suddenly split into two or more pieces after it has been resting on a floor or table without any external load being applied.

Residual stresses lead to distortion in the welded joints. This has to be controlled in order to avoid distortion. This can be reduced by clamping or by providing proper fixtures while welding.

The main parameters required are

1) Dimensions of the weld plates
2) Material properties
3) Weld temperature
4) Ambient temperature
5) Interaction properties between the metals.

IV. Weld Modelling

The weld plate of specified dimensions is created. Divide the plate in three parts by partitioning or by using cutting planes such that the required width for weld zone is indicated. Define the materials pure copper and stainless steel with properties density, thermal conductivity and specific heat capacity.

Define the sections with solid homogenous type of materials copper and stainless steel. Assign these sections to the parts of the model that are to be required to assign the properties.

The parts are to be assembled to in order to globalize the coordinates. To assemble the parts create an instance with dependent type i.e. mesh on the part.

A. Step And Interaction:

Heat transfer step and thermal analysis step is to be created in order to conduct heat analysis. The step should be solid homogenous type. The interactions are to be created at the weld pool and between the surface and the surroundings. This is done by assigning film coefficient and radiation values in surface condition and in radiation.

B. Load And Boundary Conditions:

The boundary conditions given are the ambient temperatures to the extreme surfaces. The constant boundary temperature is to be assigned. Thermal load is applied on the weld joint in the form of surface heat flux. The boundary temperature given is 27oC. The thermal load applied is 3100KJ.

C. Meshing:

The mesh tool is used and the meshing of the part is done by selecting TET element type. The size of the mesh i.e. the number of seeds the part is to be divided is to be mentioned. Then adjust the seed size and mesh the parts. Meshing of the part is done after applying the loads over the part.

D. Execution of The Input Values:

Job is created which reads all the input files and parameters given to the part. Initially the job created must be checked which verifies the data. It should be later submitted in order to analyze the solution. The results can be obtained from execution of the job.

E. Dissimilar Metal Welding – Copper and Stainless Steel:

In the Last trial, a stainless steel plate and a copper plate are modeled and are subjected to analysis. The details are as follows:

Thermal conductivity	:	200
Specific Heat	:	450
Heat flux	:	2000W

The final deformed model is as shown:

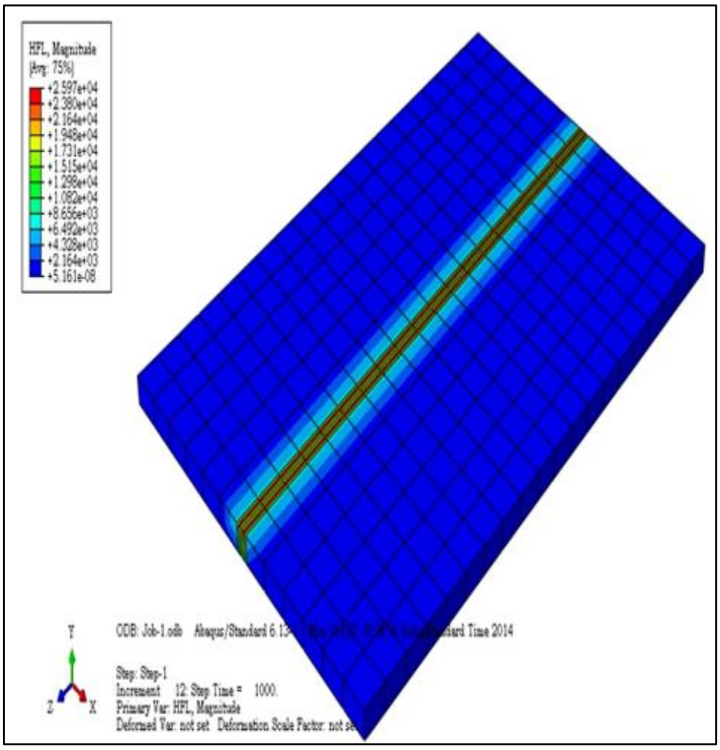

Fig. 2: S.S-Cu plate simulation

V. RESULTS AND DISCUSSION

A. The Nodal Temperatures Are Obtained As Follows:

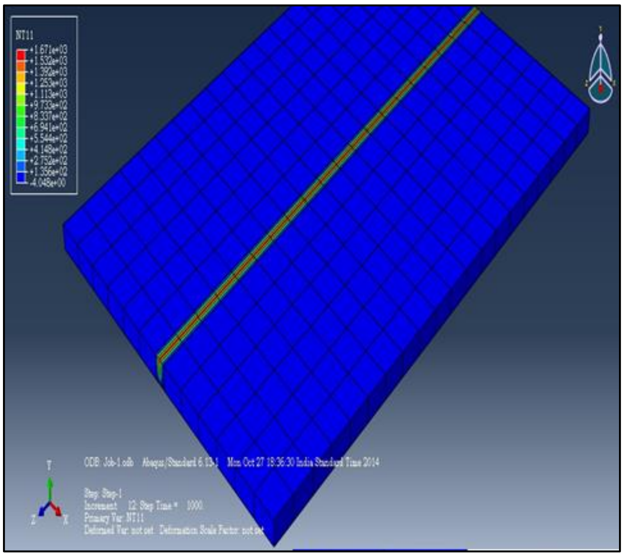

Fig. 3: NTL Values
NT – Nodal Temperatures
Maximum Temperature – 1670K

The Resultant of the Heat flux is as shown:

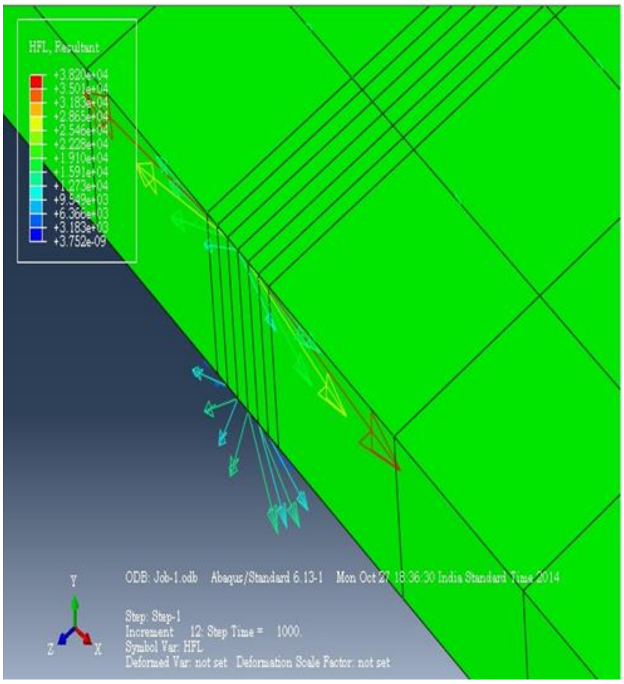

Fig. 4: HFL Resultant
HFL – Heat Flux Load
Maximum Value of HFL – 38,200

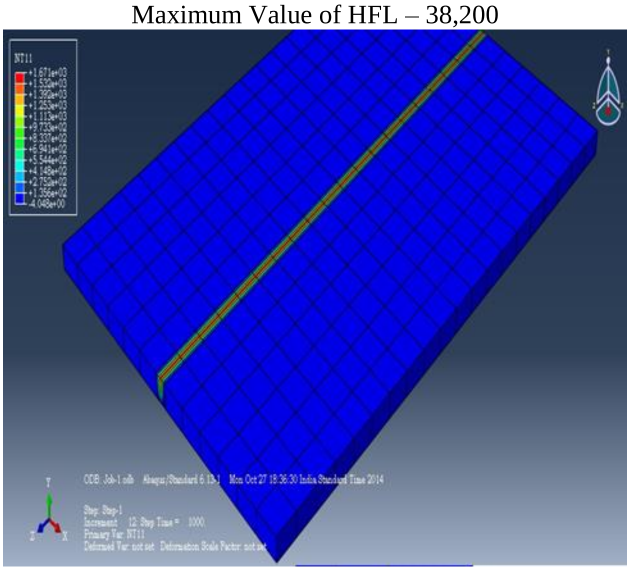

Fig. 5: Load Addition

The Load is added in 12 increments after a time of 1000 seconds
Thermal Load is distributed as shown in the figure

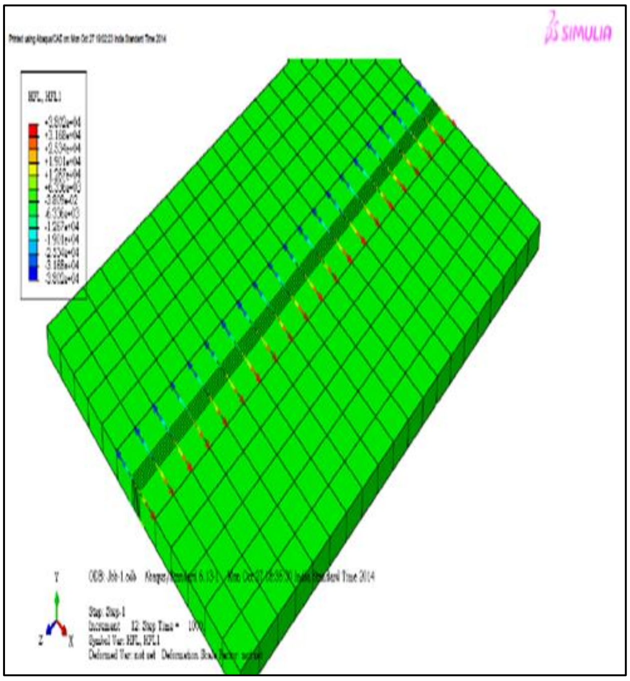

Fig. 6: Distribution of thermal load

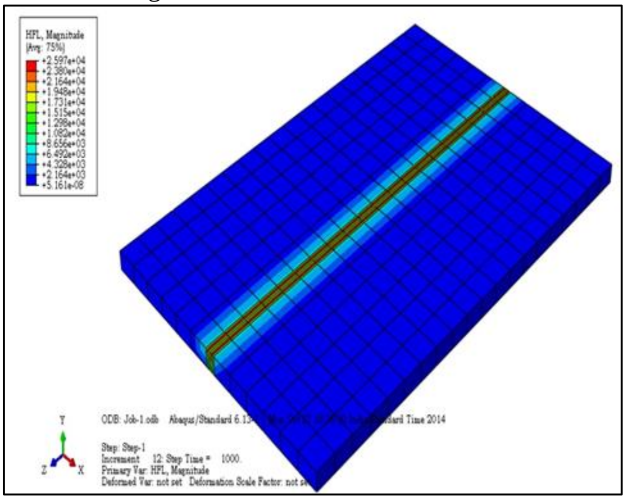

Fig. 7: Magnitude of HFL

Values of various output parameters during analysis:

WELD SPECIMEN	RESIDUAL STRESS, N/MM2
Cu – Stainless steel	Max: 1.643E09 Min: 2.198E05

Table 3: At time = 100 sec

WELD SPECIMEN	RESIDUAL STRESS, N/MM2
Cu – Stainless steel	Max: 2.881E09 Min: 3.850E05

Table 4: At time = 200 sec

WELD SPECIMEN	RESIDUAL STRESS, N/MM2
Cu – Stainless steel	Max: 3.988E09 Min: 5.308E05

Table 5: At time = 300 sec

WELD SPECIMEN	RESIDUAL STRESS, N/MM2
Cu – Stainless steel	Max: 6.034E09 Min: 7.014E05

Table 6: At time = 500 sec

Comparison of HFL values for individual experiments

Heat load, Cu-Cu Abaqus	Heat load, S.S-S.S Abaqus	Heat load, Dissimilar Abaqus
2.673E02	3.535E03	2.597E04
2.580 E02	3.259 E03	2.380 E04
2.487 E02	2.983 E03	2.164 E04
2.394 E02	2.707 E03	1.948 E04
2.301 E02	2.432 E03	1.731 E04
2.208 E02	2.196 E03	1.515 E04
2.114 E02	1.880 E03	1.298 E04
2.021 E02	1.604 E03	1.002 E04
1.928 E02	1.328 E03	8.656E03
1.835 E02	1.052E03	6.492E03
1.742 E02	7.766E04	4.328E03
1.648 E02	5.008E04	2.164E03
1.555 E02	2.290E04	5.161E-08

Table 7: ABAQUS Heat Load values

Nodal Temp, Cu-Cu Abaqus	Nodal Temp, S.S-S.S Abaqus	Nodal Temp, Dissimilar Abaqus
4.900E02	4.607E03	1.671E03
4.983 E02	4.364 E03	1.532 E03
4.975 E02	4.121 E03	1.392 E03
4.967 E02	3.878 E03	1.253 E03
4.960 E02	3.635 E03	1.113 E03
4.952 E02	3.392 E03	9.773 E02
4.945 E02	3.149 E03	8.337 E02
4.937 E02	2.906 E03	6.941 E02
4.929 E02	2.663 E03	5.544 E02
4.922 E02	2.420 E03	4.148 E02
4.914 E02	2.177 E03	2.752 E02
4.906 E02	1.933 E03	1.356 E02
4.899 E02	1.690 E03	-4.048E00

Table 8: ABAQUS Nodal Temperature values

B. Validation Graphs:

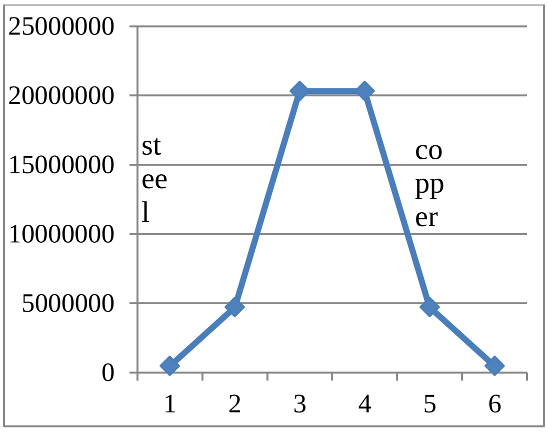

Fig. 8: Gaussian heat distribution, X-Axis: Distance (mm)   Y-Axis: Heat Flux ()

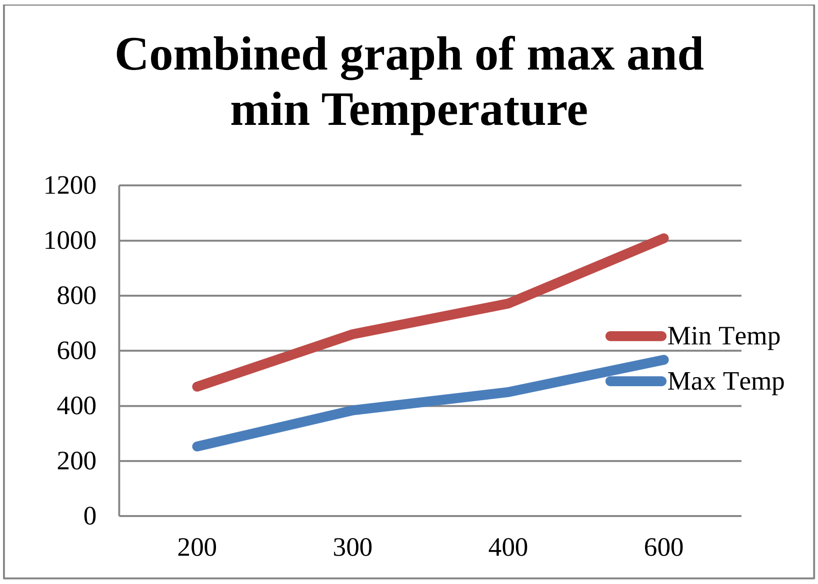

Fig. 9: Combined graph of masimum and minimum temperatures

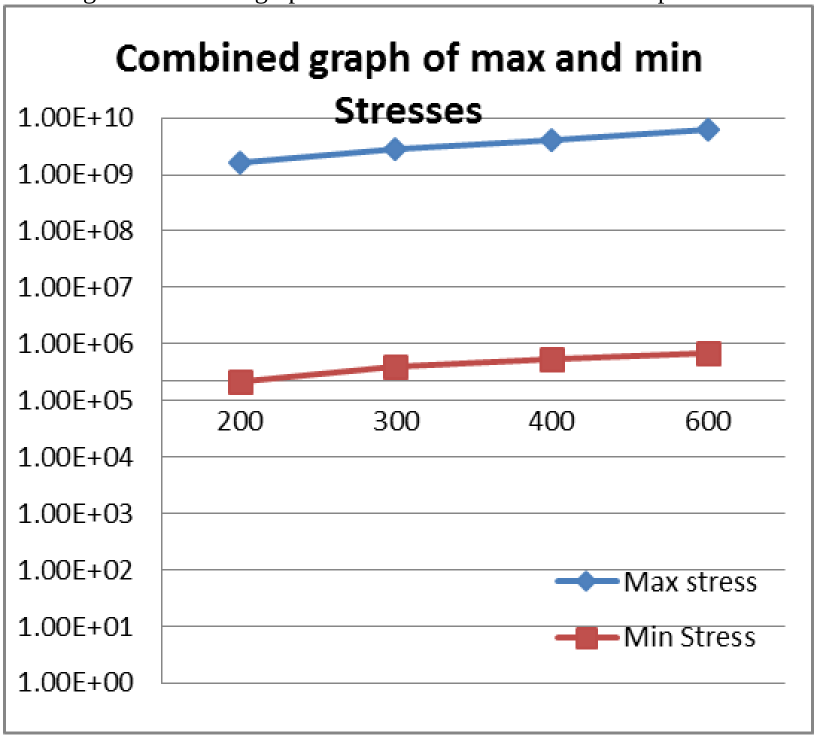

Fig. 10: Combined graph of masimum and minimum Stresses

VI. CONCLUSION

The resultant thermal flux load vector is found to be 25,970.

The highest value of temperature at nodes is 1670K found at the weld zone and the least value is 961k found towards the end of the plates.

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