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EXPERIMENTAL INVESTIGATION AND FINITE ELEMENTANALYSIS OF THERMAL DISTRIBUTION IN HEAT AFFECTEDZONE OF A588 STEEL DURING GMAW

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ABSTRACT

This research work represents a detailed study of experimental and Computational analysis of properties of the Heat Affected Zone in a Corten A588 steel when it is welded in Gas Metal Arc Welding (GMAW) without the edge preparation process and the ER70S-6 is used as filler wire. The model is subjected to Tensile and Hardness tests to study the effectiveness of the weld under these circumstances. Further, a Finite Element Method analysis is carried out to study the thermal distribution over the model and the deformation caused by the residual stress due to the thermal loads that are applied on the specimen during the welding process. The model is created in CREO and the analysis is carried out in ANSYS.
Keywords: Heat Affected Zone (HAZ); GMAW;Corten steel; thermal distribution; residual stresses; Hardness test.

INTRODUCTION (Corten STEEL)

Weathering steel, is a group of steel alloys which were developed to eradicate the need for painting, and form a firm rust-like appearance if exposed to the weather for several years. It is popularly known under the trademark "Corten steel". Corten steel is a low alloy steel with high strength that was originally developed by United States Steel in the 1930s to resist corrosion and abrasion in their ore wagons. It belongs to the low carbon steel group. The different grades of Corten steel are: (i) ASTM A242, (ii) ASTM A588, (iii) ASTM A606. Among the aforesaid grades, ASTM A588 grade is widely used for large structural construction due to its higher thickness over other grades. Hence, this research work mainly focuses on A588 grade Corten steel. Corten steel was first used in the construction of the John Deere World Headquarters building in Moline, Illinois (1964). Since then, the use of weathering steel has spread worldwide and in Europe it is available as "structural steel with improved atmospheric corrosion resistance" and is a non-proprietary product.In suitable environments weathering steel forms an adherent protective rust 'patina' that inhibits further corrosion. The corrosion-retarding effect of the protective layer is produced by the particular distribution and concentration of alloying elements in it. The protective layer on the surface develops and regenerates continuously when subjected to the influence of the weather. Further, the corrosion rate is so low that bridges fabricated from unpainted weathering steel can achieve a 120 year design life with only minimal maintenance.Therefore, a well-detailed weathering steel bridge in an appropriate environment provides an attractive, very low maintenance, economical solution and was used for many bridges around the UK. Further applications of Corten steel are outdoor sculptures (Chicago Picasso sculpture), marine transportation (in the construction of intermodal containers), etc.

BASE METAL (ASTM A588)

ASTM A588 is a high strength, low-alloy structural steel specification with improved atmospheric corrosion resistance. It is mostly used for structural steel shapes like beams,channel andangles, as well asbars and steel plate. The A588 type steel is mainlyused in welded bridges and other structures where lesser weight or improved durability is vital along with the longer life cycle owing to its corrosion resistant properties.

Table 1: Chemical composition of base metal (TYPE-A588, UNS Designation K11430)

Elements	Composition, %
Carbon	0.120
Silicon	0.298
Manganese	0.391
Phosphorus	0.087
Sulphur	0.013
Chromium	0.546
Nickel	0.218
Copper	0.302

Table 2: Thermal and mechanical properties of base metal (TYPE-A588, UNS Designation K11430)

Co-efficient of Thermal Expansion (1/K)	6.5×10^{-6}
Thermal Conductivity (W/m-K)	42
Tensile Strength MPa	480
Young's Modulus (MPa)	2×10^{5}
Poisson ratio	0.30
Density (kg/mm3)	7.85×10^{3}

Melting Temperature (ºC)	1372-1510

FILLER MATERIAL (ER70S-6)

ER70S-6 is a mild steel solid wire developed to provide high quality welds and problem-free performance ranging from heavy duty-fast spray transfer applications to light duty-slow short-arc processes. ER70S-6 is created for using with numerous gas mixtures such as 100% CO2, 75/25 Ar/CO2 or 98/2 Ar/O2. Even in the most complex applications, ER70S-6 givesanevensteady arc with low spatter, creating a weld bead that ties in evenly with the sides and has a smooth finished appearance.

Table 3: Chemical composition of filler wire (TYPE ER70S-6, UNS Designation K11140)

Elements	Composition, %
Carbon	0.10
Silicon	0.80
Molybdenum	0.12
Sulphur	0.03
Chromium	0.15
Nickel	0.13
Copper	0.50

GAS METAL ARC WELDING:

Gas metal arc welding (GMAW), sometimes referred to by its subtypes metal inert gas (MIG) welding or metal active gas (MAG) welding, can be defined as a welding process in which an electric arc is created in between a consumable wire electrode and the work piece metal(s).This arcproduces heat that melts the work piece metal(s), and merges it together. A shielding gas is fed through the welding gun along with the wire electrode.This shields the process from aircontaminations. The process can be semi-automated or automated. A constant volt, DC power source is mostly used with GMAW. HoweverAC power source /constant current systems can be used too. There are four major methods of metal transfer in GMAW. They are globular, short-circuiting, spray, and pulsed-spray. Each of aforesaid methods has distinct properties and corresponding pros and cons.

EXPERIMENTAL WORK

SAMPLE PREPARATION:

The sample preparation process involves three main steps namely, Cutting, Cleaning and Polishing. Initially the sample plates are cut into a dimension of 300 x 300mm with the help of wire cut EDM machine.Then the sample is cleaned usingacetone solutionand cotton cloth. Then the plates are polished using 120 Emery wheel and Silicon Carbide powder. The finished plates are used for the Welding Process on which the further study is carried out.

DESCRIPTION OF WELDED PLATES:

The Table4provides information about the parameters under consideration while performing the Gas metal arc welding of Corten A588 X Corten A588 (without edge preparation). It includes the parameters like current, voltage, shielding gas, time, root gap etc.

Table 4: EXPERIMENTAL PROCEDURE AND OBSERVATION

Description	"Corten A588 X Corten A588"
Type of welding	GMAW
Current (Amps)	172
Voltage (volts)	19
Filler wire	ER70S-6
FillerRod Dia(mm)	1
Shieldinggas	CO_2 99.95%
Gas flow rate (lpm)	16
Root gap (mm)	3
Time taken (sec)	160
Weld Length (mm)	300
Welding speed(mm/s)	1.9

EXPERIMENTAL RESULTS:

The Experimental results include three different tests, namely Micro structural Study, Hardness test and Tensile test of the welded plates.

MICRO STRUCTURAL STUDY OF THE SPECIMEN

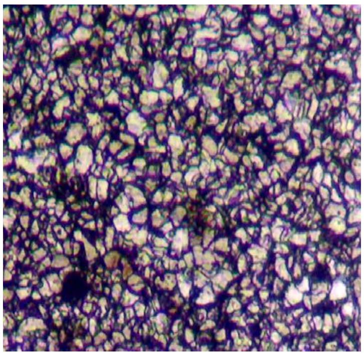

Fig 1: Base metal (100 X Magnification)

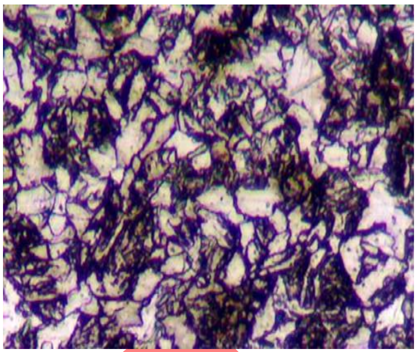

Fig 2:HAZ (100 X Magnification)

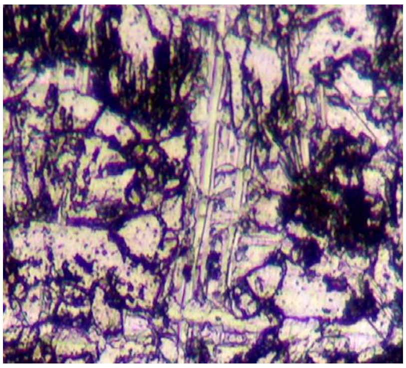

Fig 3: Weld metal (100 X Magnification*)*

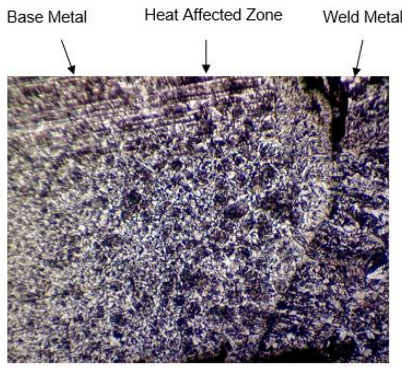

Fig 4: Base Metal, HAZ & Weld Metal Interface

The microstructural properties of the specimen can be inferred from the above figures. Fig 1,2&3 represents microscopic views (at 100x magnification) of base metal, HAZ and Weld metal respectively. Fig 4 represents the interface view of all aforesaid metals. From fig 1, it can be observed that the grains are smaller in size and are arranged in a uniform manner. From fig 2, it can be observed that the grains are large in size and are arranged in an irregular manner. From fig 3, it can be observed that the grains are much larger in size and are arranged in an irregular manner. The difference in grain size and in the arrangement of grains on different zones of the specimen is due to the difference in temperature at various zones during welding. The highest temperature can be observed at weld metal zone, the lowest temperature can be observed in base metal zone and the temperature of the HAZ falls in between.

Table 5: Observation of average HAZ width and Weld width

Description		“Corten A588 X Corten A588”
Average HAZ width (mm)		1.3
Weld width	**Top**	8.0

(mm)	**Middle**	6.0
	Bottom	4.0

From table 5, it can be observed that the average Heat Affected Zone width and Weld width for the Corten Steel is 1.30 mm and 6 mm respectively, when the specimen is welded under the parameters mentioned on table5.

Hardness Test on various zones of the specimen:

The Vickers hardness test is carried out to determine the hardness of the welded plates. The table 6 lists the Vickers Hardness number obtained at various locations of the sample after the welding process. And the obtained results are visualized in the form of line chart while taking location of the hardness measured along the horizontal axis and Hardness number along the vertical axis.

Table 6: Vickers hardness test results of various zones of the specimen

Description	"Corten A588 X Corten A588"
(Location in weld)	HVN(1 kg)
Parent Metal	188.3
Parent Metal	185.4
Heat Affected Zone	173.7
Heat Affected Zone	166.1
Weld Zone	189.4
Weld Zone	199.1
Weld Zone	193.5
Heat Affected Zone	169.3
Heat Affected Zone	172.4
Parent Metal	185.5
Parent Metal	189.7

From the table 6, it can be observed that the Highest Vickers hardness number occurs at the Weld Zone whereas the lowest HVN occurs at Heat Affected Zone.

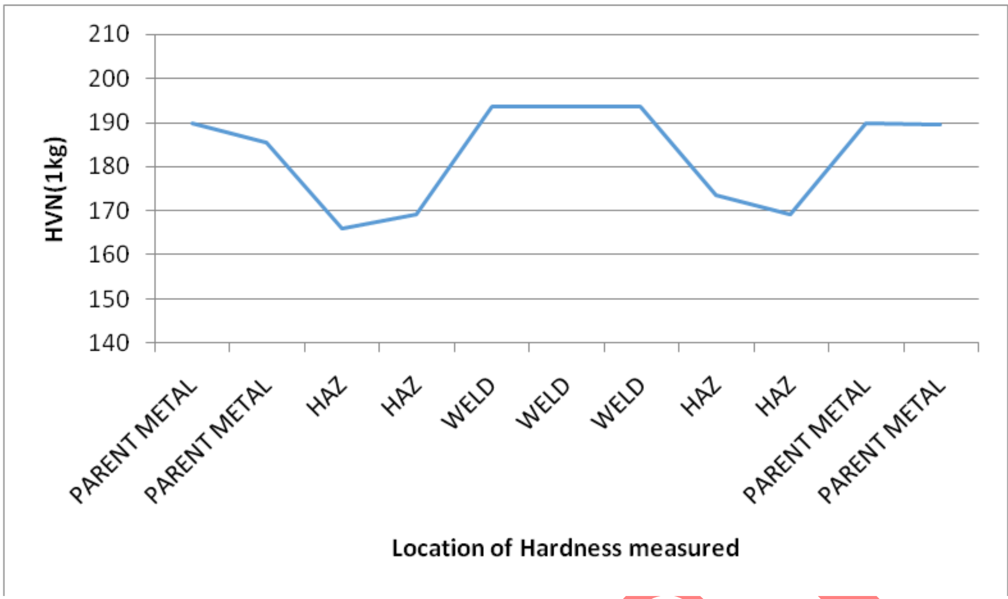

Fig 5: Vickers hardness test graphof various zones of the specimen

Tensile Test on the specimen:

The specimen to be tested in UTM is cut from the whole welded plate by following ASTM E8/E8-M – 11 standards.A tensile load is applied to the prepared specimen until it fractures. During the test, the loadsacting on the specimen and the corresponding elongationsof the material are recorded. A load elongation curve is plotted by an x-y recorder, so that the tensile behavior of the material can be obtained. The table7mentioned below provides information about the Ultimate Tensile Strength of the Sample and the Fracture location.

Table 7:Tensile test results

Description	“Corten A588 X Corten A588”
Ultimate tensile strength (Mpa)	577.09
Fracture Location	Base

FINITE ELEMENT ANALYSIS:

Model and Drawing Preparation:

Model and Drawing was created in CREO with a dimension of 300x300mm as shown in fig 6

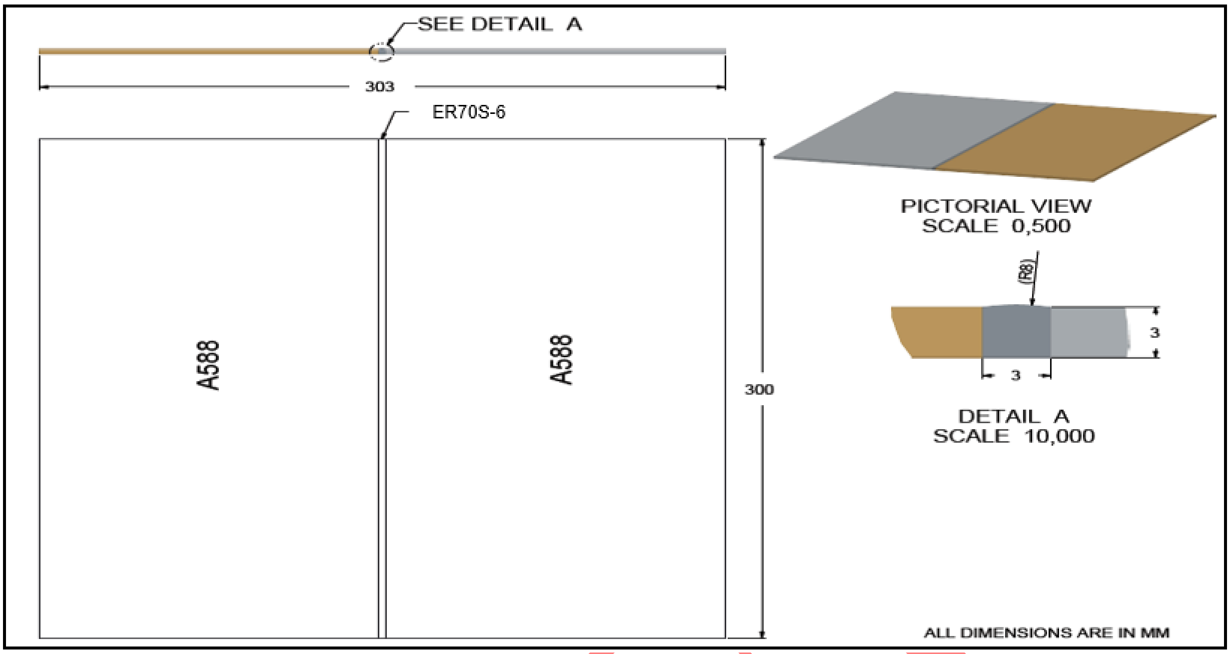

Fig 6: A588 X A588 without edge preparation

Thermal boundary conditions and Load Cases:

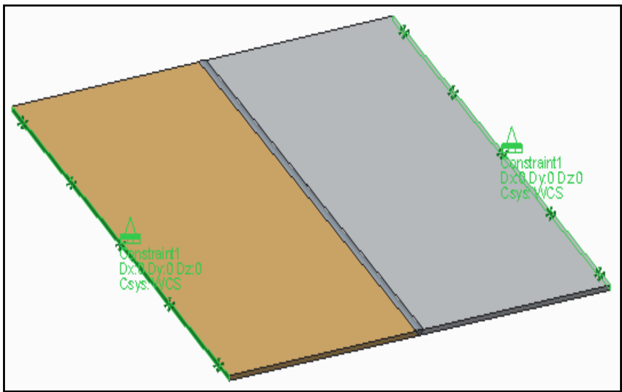

Fig 7: Constraint of the model

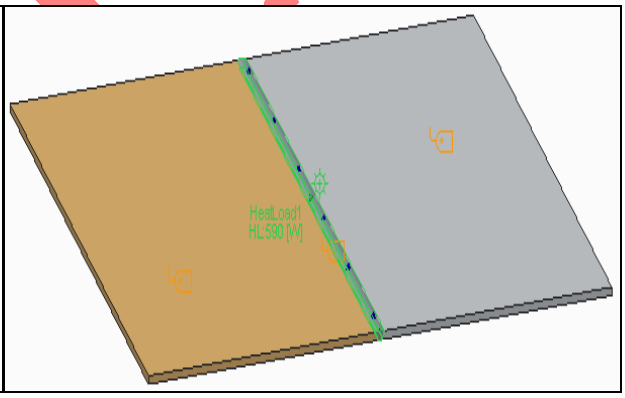

Fig 8: Thermal load

Thermal Load and Heat Flux Calculation:

Heat input can be defined as the ratio of the arc power supplied to the electrode to the arc travel speed, as shown in the following equation (if the arc efficiency is neglected)

$$Q = \frac{V \times I \times 60}{S}$$

Where, Q = Heat input in watts

V = Welding arc voltage in volts

I = Welding Current in amps

S = Arc welding speed in mm/min

Heat input and Heat flux can be calculated as follows

$$Q = \frac{V \times I \times 60}{S} = \frac{19 \times 172 \times 60}{114} = 1720\ W$$

$$q = \frac{Q}{a} = \frac{1720}{0.78 \times 10^{-6}} = 22.05 \times 10^{8} W/m^{2}$$

Model generation for the Tensile Test:

The Fig 9 represents the geometrical model of the specimen to be analyzed. The dimensions of the model were fixed in accordance with ASTM E8/E8-M – 11 standards.

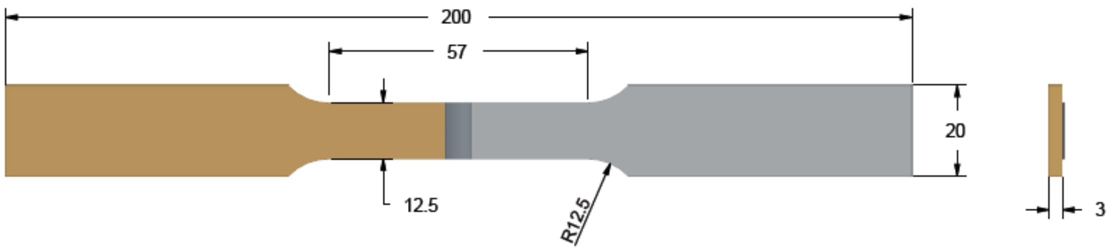

Fig 9: Model for Tensile test

Boundary conditions and Load Cases for Tensile test:

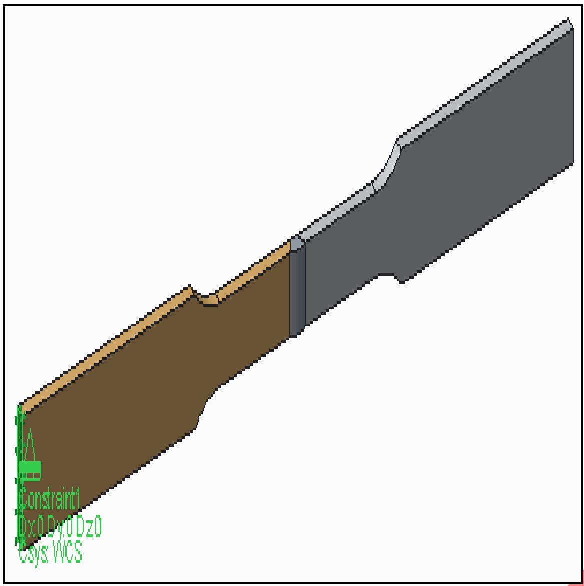

Fig10:Constraint for the model

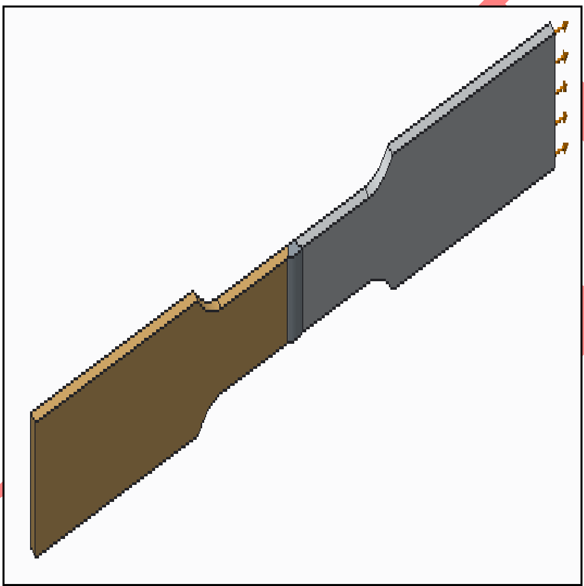

Fig 11: Tensile load applied on the model

RESULTS OF THE FINITE ELEMENT ANALYSIS:

The following Figures represents to study the thermal distribution over the model and the deformation caused by the residual stresses due to the thermal loads that are applied on the specimen during the welding process.

Thermal distribution of the model:

The fig 12 represents the computationally simulated thermal distribution throughout the specimen under the Heat flux,q = . It can be observed that the temperature is maximum at the weld zone (1510 ℃) and gradually decreases while moving away from the weld zone.

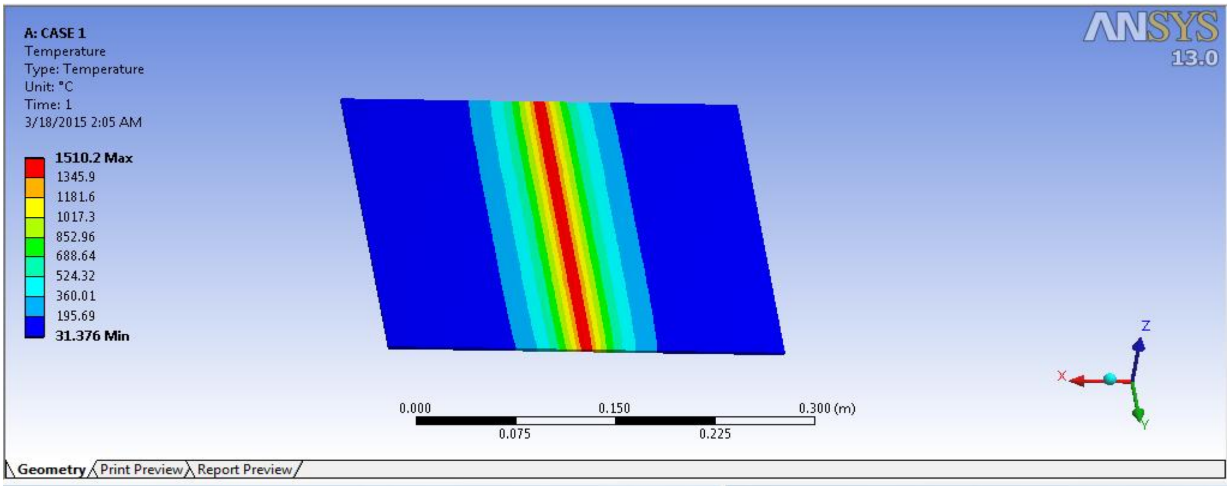

Fig 12:Thermaldistribution of the model

The fig 13 is the graphical representation of the temperature throughout the length of the specimen. It can be observed that temperature variation is effective only at a distance of 50mm from the weld zone on both sides, after whichthe temperature variation is minimal or negligible.

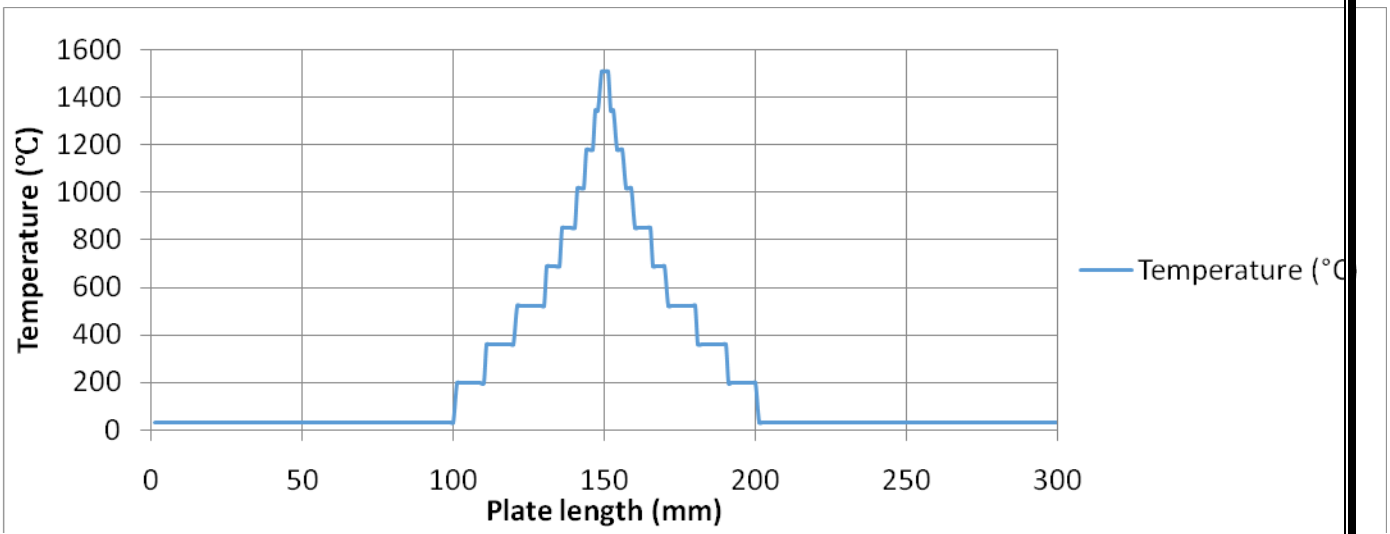

Fig 13: Temperature vs. Plate length for the specimen

DEFORMATION DUE TO THERMAL LOAD IN THE MODEL:

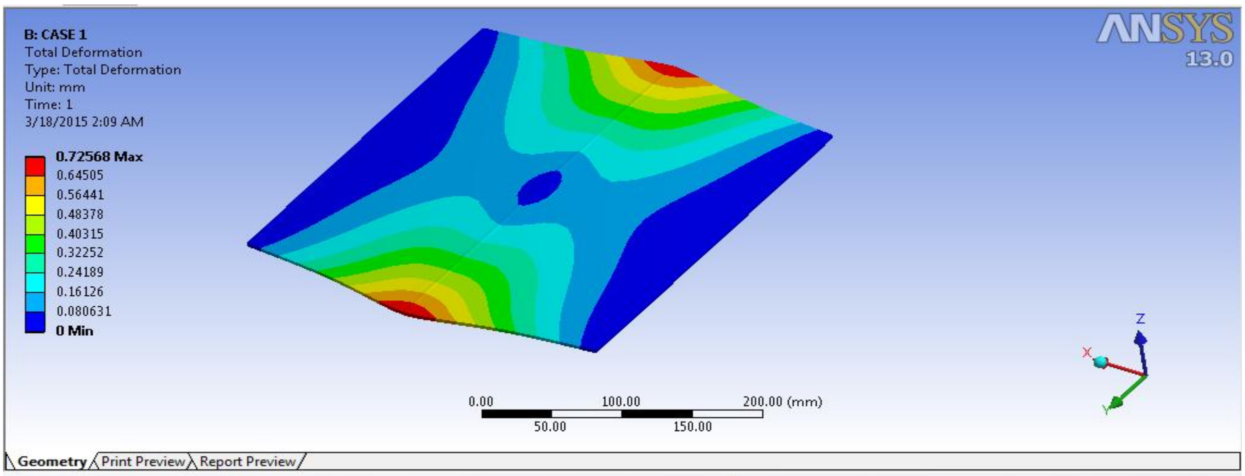

Fig14: Deformation due to thermal load in the model

It is observed from the Fig 14 that when a heat flux of is applied on the Weld surface, a distortion of 0.725mm is observed on the both ends of weld length.

RESIDUAL STRESS DUE TO THERMAL LOAD IN THE MODEL:

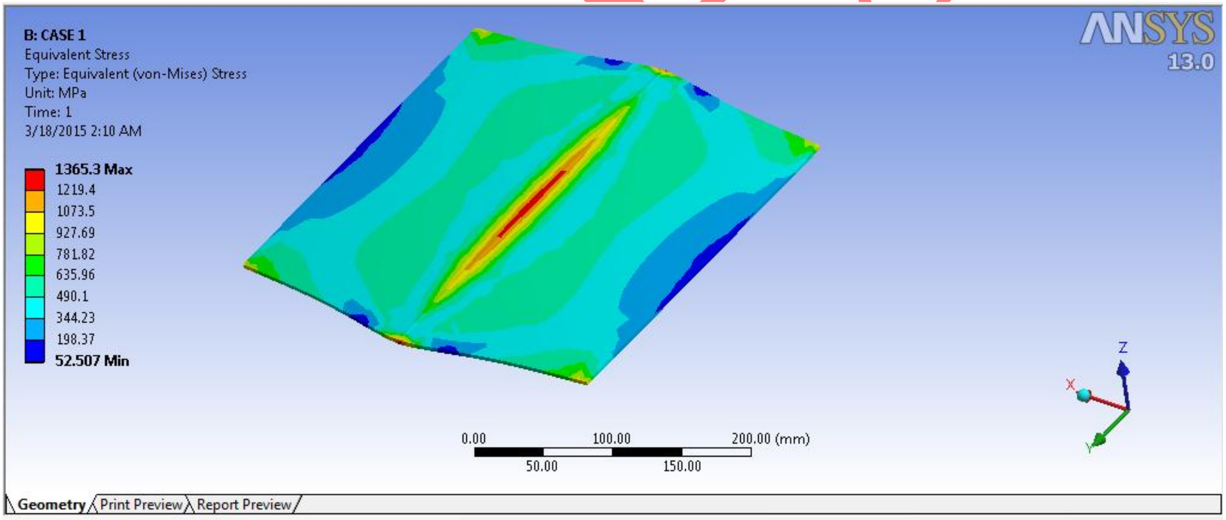

Fig 15: Residual stress due to thermal load in the model

It is observed from the Figure 15 that when a heat flux of is applied on the Weld surface, amaximum residual stress of 1365.3 MPa is observed at the center of the Weld zone.

Table 8:Thermaltest results

Description	“Corten A588 X Corten A588”
Heat Flux (W/m^2)	22.05×10^8
Maximum Residual Stress (MPa)	1365.3
Maximum Deformation (mm)	0.725

TENSILE STRESS DUE TO TENSILE LOAD:

From fig 16 it can be observed that when the tensile load of 16879 N is applied on the both ends of the weldment in opposite direction, a maximum tensile stress of 577 MPa is observed at the base metal.

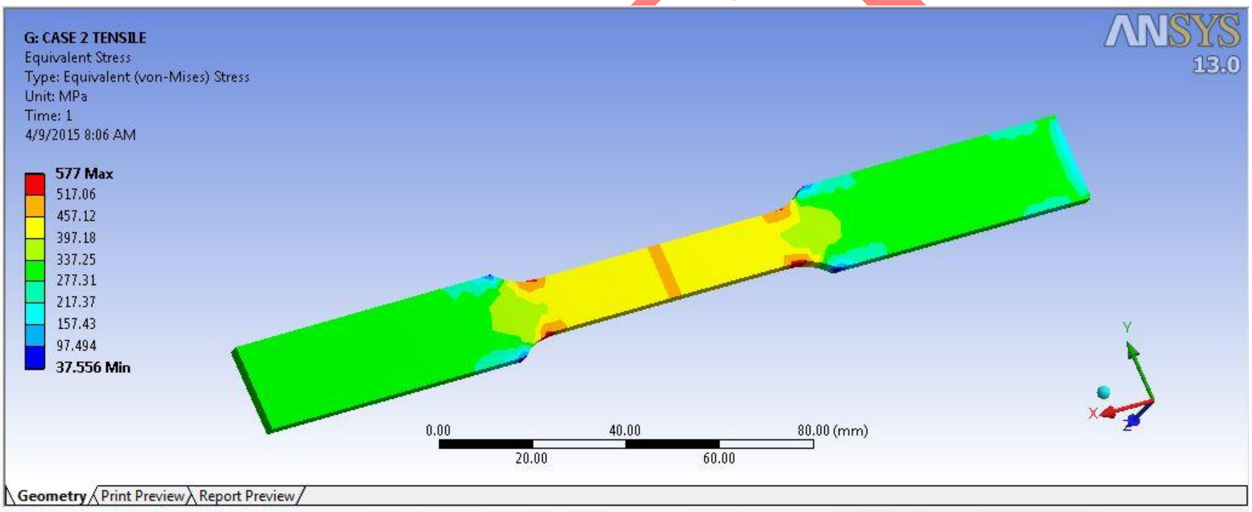

Fig 16: Tensile stress due to tensile load

DEFORMATION DUE TO TENSILE LOAD:

From the figure 17 it can be observed that when the tensile load of 16879 N is applied on the one end of the weldment and other end was fixed, a maximum deformation of 0.344mm is observed at one extreme end where the tensile load was applied.

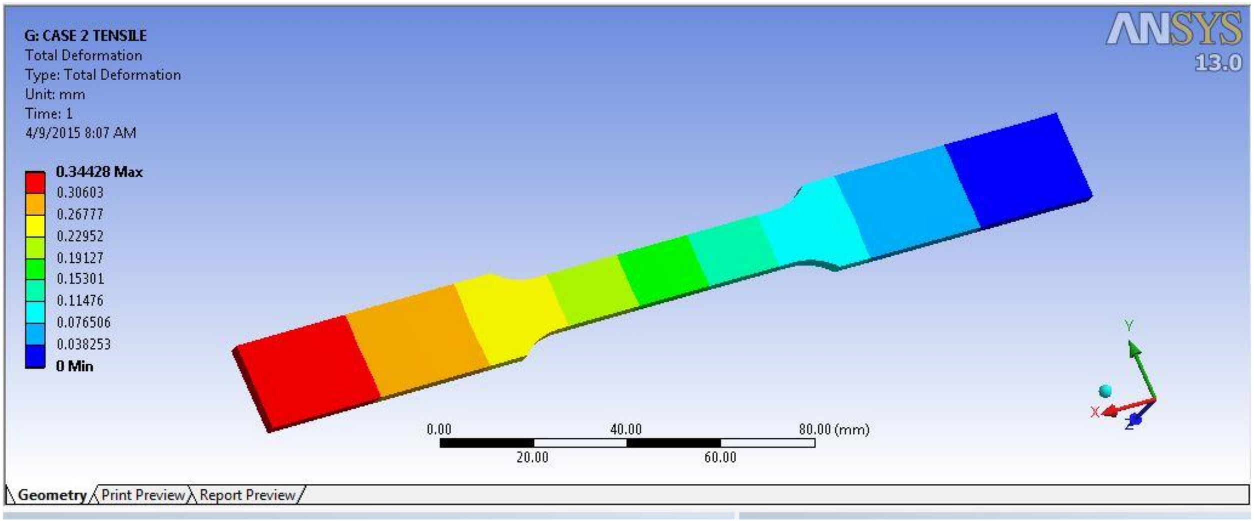

Fig 17: Deformation due to tensile load

Table 9: Tensile test results

Description	"Corten A588 X Corten A588"
Tensile load (kN)	16.9
Ultimate Tensile Strength (MPa)	577
Deformation (mm)	0.344

CONCLUSION

Based on the Study conducted on theexperimental and Computational analysis of properties of the Heat Affected Zone in a Base metal when it is welded in Gas Metal Arc Welding (GMAW) without the edge preparation process,it was observed thatthe Highest Vickers hardness number occurs at the Weld Zone whereas the lowest HVN occurs at Heat Affected Zone.However, when a heat flux of and is applied on the Weld surface, a distortion of 0.725mm is observed on the both ends weld length and a maximum residual stress of 1365.3 MPa is observed at the base metal. Further, it can be observed that the average Heat Affected Zone width and Weld width for the Corten Steel is 1.30 mm and 6 mm respectively, when specimen is welded under the aforesaid parameters.

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