

### Article Info

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## Applicability of Finite Element Method for Prediction of Stress Concentration on Welded Joints with Defects

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### ABSTRACT

Uncertainty in manufacturing process, methodologies and environmental factors will lead to occurrence of flaws in the welded structures. Certain critical weld defects like lack of fusion, slag inclusion and cold cracks embedded during welding will impact the structural life of the structures. Planar defects have to be considered seriously than volumetric defects. An attempt is made to study the effect of weld defects on the structural integrity of components. The experimentation was conducted on the butt joint specimen and it is on par with numerical results. The present work involves the applicability of the finite element method to predict the stress on welding joints with defects using a finite element software and compare results with weldments with zero defects. The defects are simulated experimentally and similar defects are measured using radiography and the same in modelled numerically to predict the stress induced in specimens.

**Keywords:** Welding; Defects; Finite Element Method; Stress Analysis;

### 1.0 Introduction

Welding represents one of the most complex manufacturing processes in terms of number of variables involved and factors contributing to the final output. Welding however, induces thermal strains in the weld metal and base metal regions near the weld, resulting in stresses and distortions[1].

One of the major mechanical effect of welding i.e. defect which is mainly focused in this paper. The major types of welding defects are slag inclusion, porosity, crack formation, lack of fusion, lack of penetration and undercuts. A model has been established to simulate the stress in welding joints considering porosity and cold cracks which is considered to be most commonly occurring during the metal arc welding[2]. The variables related to welded joints are as follows[3]:

1. Strength of deposited weld material.
2. Type of joint and weld.
3. Size of weld.
4. Location of connecting parts
5. Types of stress the weld is subjected

6. Conditions under which weld is carried out.
7. Type of welding process employed.

Porosity is a collective name describing the cavities or pores caused by gas entrapment and employment of hygroscopic filler rods. This is mainly occurring when we use electrode E7018 which made of low hydrogen potassium iron powder without baking. This causes excessive hydrogen in welding atmosphere, High solidification rate and rapid freezing of weld metal, dirty base metal and filler material (oil or grease), excessive moisture in electrode[4].

Cold cracking is cracking that occurs as the result of hydrogen dissolving in the weld metal and then diffusing into the heat affected zone (HAZ). Cold cracks mostly develop long after the weld metal solidifies, but sometimes appear sooner. Cold weld cracking occurs at temperatures well below 600°F. It is considered a serious welding defect because it can significantly affect the integrity of weldments. Cold cracking is also known as hydrogen-induced cracking, delayed cracking or under-bead cracking. The above mentioned parameters were used for obtaining cold cracks in the specimen.

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A nonlinear analysis is needed if the loading on a structure causes significant changes in stiffness. Typical reasons for stiffness to change significantly are [6]:

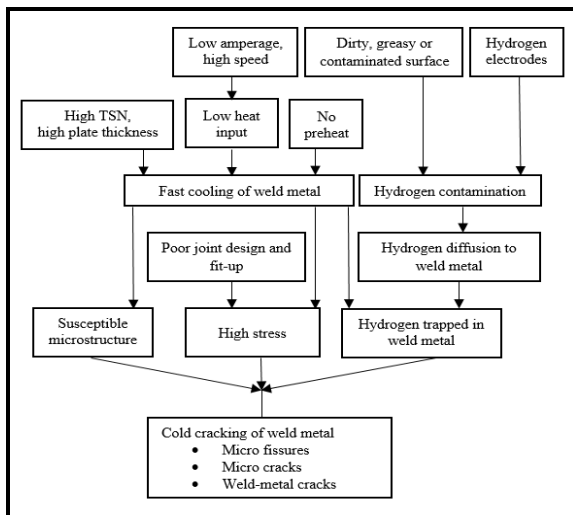
1. Strains beyond the elastic limit (plasticity)
2. Large deflections, such as with a loaded fishing rod
3. Contact between two bodies

When a large force is applied resulting in a stresses greater than yield strength, a case where multi-linear stress-strain relationship can be included which follows the stress-strain curve of the material being used as shown in fig. 3. This will allow finite element modeler to accurately model the plastic deformation of the material.

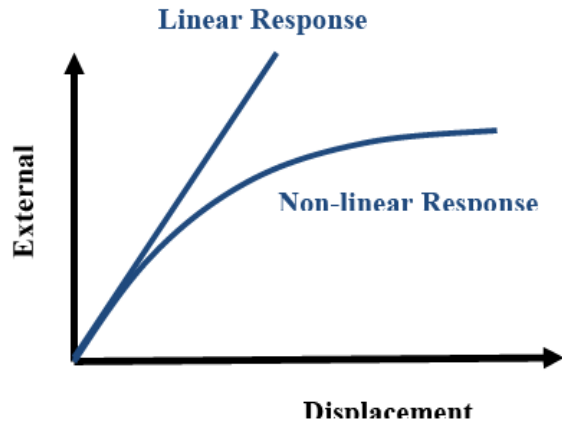
**Fig 1: Porosity in Welded Joints**



**Fig 2: Causes for Cold Crack Formation[5]**

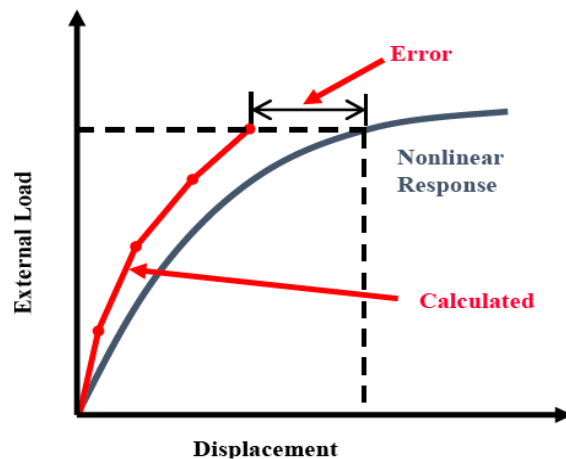


**Fig 3: External Load-Displacement Curve of Linear and Non-Linear Response**



One approach is to apply the load gradually by dividing it into a series of increments and adjusting the stiffness matrix at the end of each increment as shown in fig. 4. The problem with this approach is that errors accumulate with each load increment, causing the final results to be out of equilibrium.

**Fig 4: External Load-Displacement Curve of Calculated and Non-Linear Response**



The finite element solver used here is ANSYS Which uses the Newton-Raphson algorithm to solve the nonlinear problems. Using this algorithm, the load is gradually applied in increments. Also performs equilibrium iterations at each load increment to drive the incremental solution to equilibrium. This algorithm solves the equation (1) as given below,

$$[K_T]\{\Delta_u\} = \{F\} - \{F_{nr}\} \quad (1)$$

where,  $K_T$  = tangent stiffness matrix

$\Delta_u$  = displacement increment

$F$  = external load vector

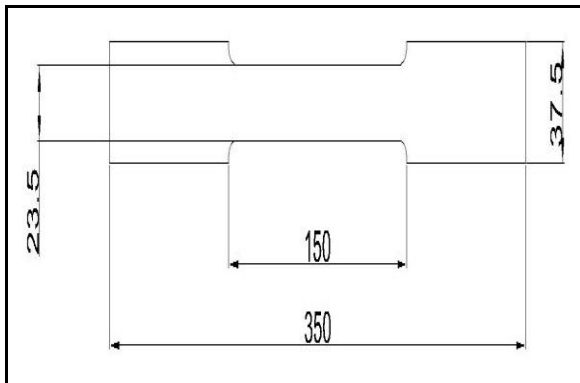
$F_{nr}$  = internal force vector

Iterations continue until difference between external and internal loads is within a tolerance limits. In the initial phase the numerical results are validated with experimental results.

## 2.0 Experimentation

The tensile test is conducted on specimen having SA 516 Gr.70 (ASME Sec IX QW-422) material having nominal composition of C-Mn-Si with thickness of 17mm is fabricated as per the fig. 5.

**Fig 5: Tensile Test Specimen Dimensions**



The results obtained from tensile test on the parent material, weld specimen and all weld specimens are given in Tables 1, 2 and 3. The tensile strength, yield stress and load at peak for parent material is presented in Table 4.

**Table 1: Stress-Strain Results for Parent Material**

Sl.No.	Stress(N/mm <sup>2</sup> )	Strain
1	20	0.02
2	70	0.08
3	150	0.10
4	240	0.12
5	460	0.20
6	535	0.32
7	535	0.34
8	490	0.38

**Table 2: Stress-Strain Results for Welded Specimen**

Sl.No.	Stress(N/mm <sup>2</sup> )	Strain
1	40	0.60
2	140	0.80
3	200	0.90
4	300	0.10
5	500	0.22
6	510	0.30
7	510	0.31
8	490	0.40

**Table 3: Stress-strain results for all weld specimen**

Sl.No.	Stress(N/mm <sup>2</sup> )	Strain
1	76	0.04
2	100	0.05
3	150	0.07
4	200	0.08
5	300	0.10
6	400	0.12
7	500	0.20
8	530	0.30
9	530	0.32
10	510	0.40

**Table 4: Comparison of Tensile Test Results**

Contents	Parent material specimen	Welded material specimen	All Weld specimen
Tensile Strength (MPa)	544	519	551
Yield Strength (MPa)	355	369	432
Load at peak (kN)	213	203	44

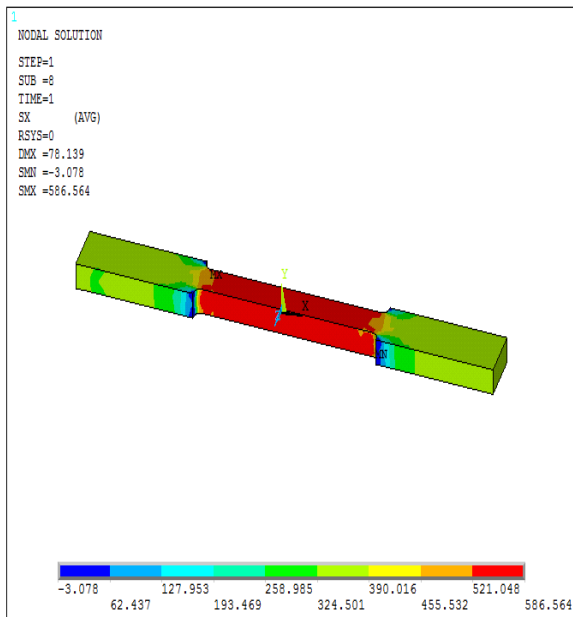
## 3.0 Finite Element Analysis

For carrying out non-linear analysis within the elastic limit, linear material property with Young's modulus and Poisson's ratio of  $2 \times 10^5$  N/mm<sup>2</sup> and 0.3 respectively is considered as material property. Above the elastic limit, the results obtained from tensile test are incorporated in multi-linear analysis column in finite element solver.

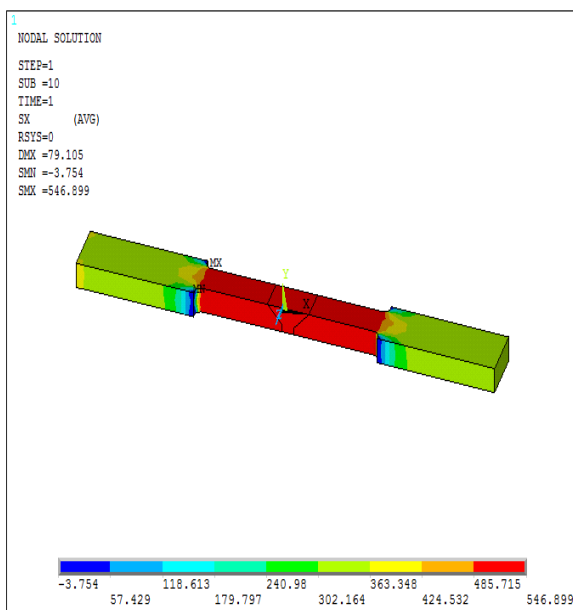
### 3.1 Validation of parent and weld metal test results

A finite element analysis is run for the model prepared for parent and weld materials. The stress results are obtained for parent and weld materials as shown in figures 6 and 7 respectively.

**Fig 6: Stress Plot of Parent Material**



**Fig 7: Stress Plot of Welded Specimen**



**Table 5: Comparison of Experimental and Numerical Results for Parent Material**

	Experimental Result	Numerical Result
Tensile strength(MPa)	544	586

From the numerical results it is clear that the FEM results is on par with experimental results with an error of 7%.

**Table 6: Comparison of Experimental and Numerical Results of Weld Material**

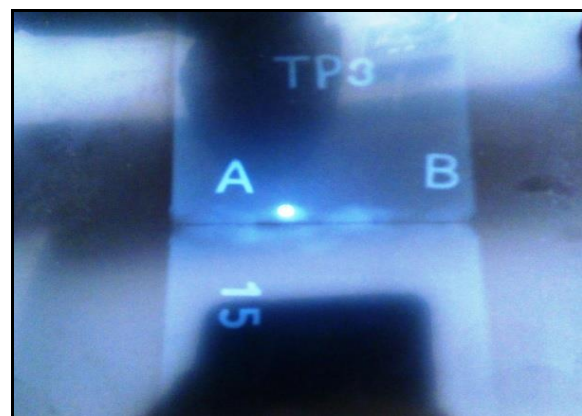
	Experimental Result	Numerical Result
Tensile strength(MPa)	519	546

The above the results are validated. Here, presence of volumetric percentage of parent metal present in weldment is not taken into account which requires metallurgical considerations to a greater extent.

### 3.2 Prediction of stress for welded specimen with porosity and cold cracks

From the radiographic testing the presence of porosity is ensured and the dimension for porosity is obtained from radiographic images as shown in figures 8 and 9 respectively.

**Fig 8: Radiography Test Result Porosity Specimen**



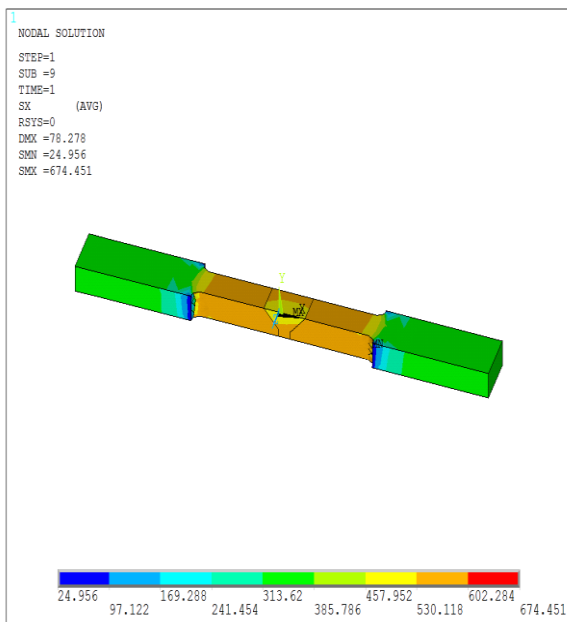
**Fig 9: Radiography Test Result on Cold Crack Specimen**



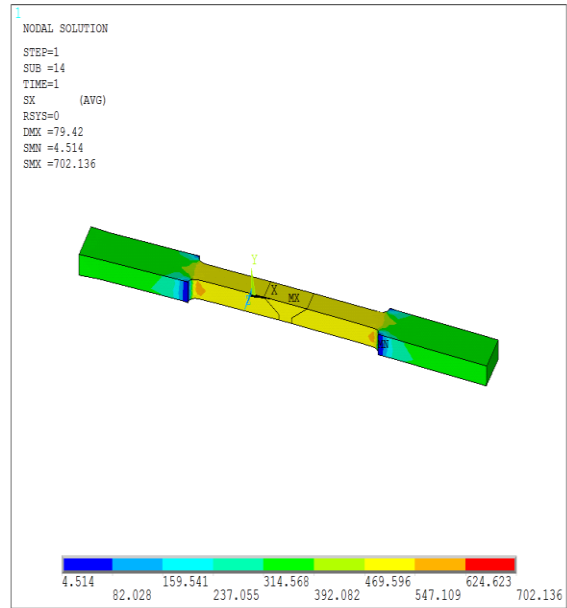
Similarly, a finite element analysis is conducted for the model with porosity and cold cracks. The stress results are obtained for model with porosity and cold cracks as shown in figures 10 and 11 respectively.

Since the validation for parent metal and weld specimen properties were on par with finite element software results, the predicted value for weldment with porosity and crack can be directly taken for consideration.

**Fig 10 Stress Plot of Specimen with Porosity**



**Fig 11: Stress plot of specimen with cold cracks**



**Table 5: Comparison of Numerical Results of Porosity and Cold Crack**

	Weld Defect	
	Porosity	Cold Cracks
Tensile strength(MPa)	530	469

#### 4.0 Conclusions

The experimental results carried out on the specimen as per the standard subjected to UTM testing is in line with numerical method adopted. This work is extended for analyzing the properties in weld specimen with defects such as porosity and crack. With the confidence level of modeling the actual prototype of welding we can extend the same work for specimen with defects.

In the presence of defect, the material generally tends to weak. It is also inferred that volumetric defect results in decrease of tensile strength of a weldment.

The present work can be extended for predicting the fatigue life of welded components numerically for components with different geometries considering weld defects.

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