Review on Determination of residual stress in Weldments

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Abstract - This paper presents the literature review on determination of welding residual stresses in weldments. In this paper, a detailed study on residual stress and the different methods to determine the residual stresses is carried out. There are different cases dealt in this study. The specimen is mainly steel pipe. It is cut into two and the ends are grooved with an opening angle of 45°C and the ends are welded together. This is the region where the residual stresses will be induced and the different methods in which residual stresses can be found is discussed. The main objective of this review is to describe about the several types of methods to determine the residual stresses in steel pipes and to find a suitable method to determine the residual stress in low carbon steel pipes which are welded using MIG welding.

Key Words: Residual stress, MIG welding, Low carbon steel pipes, Weldments

1. INTRODUCTION

1.1. Residual stress:

Olabi et al in their paper stated that residual stresses are stresses that remain in a solid material after the original cause of the stresses has been removed. Residual stress may be desirable or undesirable. Residual stresses can occur through a variety of mechanisms including inelastic (plastic) deformations, temperature gradients (during thermal cycle) or structural changes (phase transformation) [1]. Tso – Liang stated in their experiment that heat from welding may cause localized expansion, which is taken up during welding by either the molten metal or the placement of parts being welded. When the finished weldment cools, some areas cool and contract more than others, leaving residual stresses. [2]

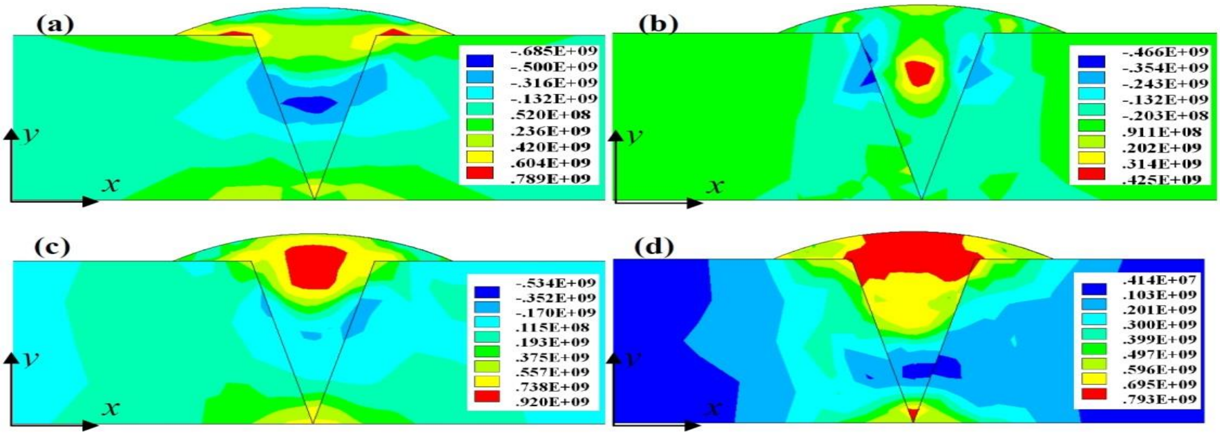
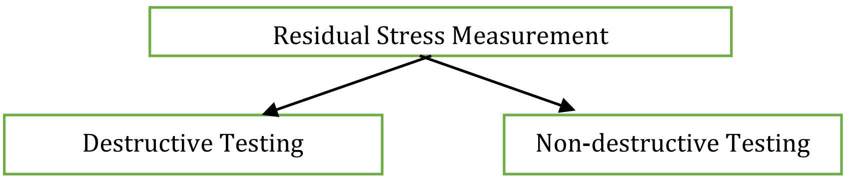


Fig 1. Residual stress induced during welding

2. LITERATURE REVIEW

2.1. Types of methods



Rossini et al in their paper explained about the several types of methods available to determine the residual stress. They are divided into Non-destructive methods (X-Ray Diffraction method, Ultrasonic method and Finite element method) and destructive methods (Hole drilling method) which are used to determine residual stresses are discussed. [3]

2.2. X-ray diffraction method

Neubert et al discussed the effects of non-uniform martensitic transformation and subsequently leading to the formation of residual stress **[4].** They also developed a numerical method to determine the residual stress and compared the results obtained by using X-ray diffraction method and numerical method. The material that is chosen is low alloyed high strength steel as base material and super-martensitic high alloyed filler material.

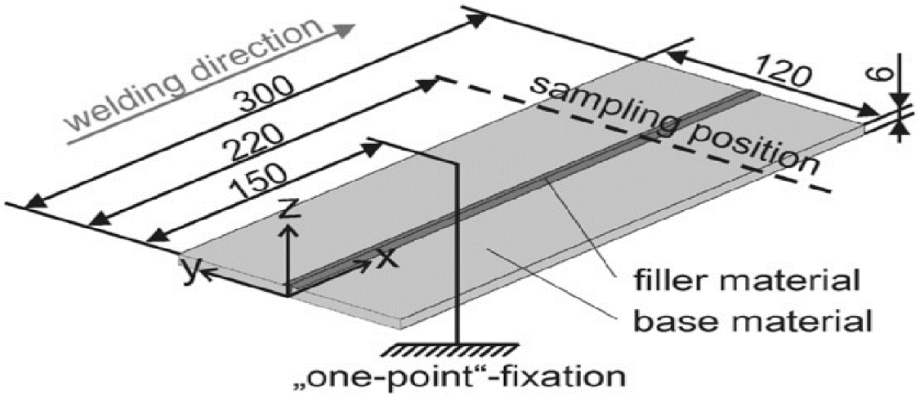


Fig 2. Work piece setting to study effects of non-uniform martensitic transformation on residual stress

Single pass butt welds were carried out by using GMA Welding. The Residual stress is determined by using X-ray diffraction method and transient weld distortion was measured by using ARAMIS system. Cross-sections perpendicular to weld seam were produced to determine the weld pool geometry and solid phase distribution.

The wire feed rate of the GMA process was 9 m/min. The single-pass butt welds were performed using a V-groove preparation with an opening angle of 30°C. Residual stresses were determined by X-ray diffraction method using $\sin^2(\psi)$ method on the top and bottom surface at the sampling position. [5]

2.3. Ultrasonic method

Bray et al in their experiment used a linear relationship between the velocity of ultrasonic wave and the stress of material to determine the residual stress. This relationship, within the elastic limit, is the acoustoelastic effect which gives the time of flight [9].

It is evident that when a longitudinal wave passes through an interface between two materials, there is an incident angle that makes the angle of refraction for the wave 90°C. It can be shown that sensitivity of the L_{CR} waves to the strain is highest amongst the other types of ultrasonic waves. By using the time of flight within the material, the amount of strain can be calculated, since the flight time varies with the amount of strain present.

Yashar et al developed a 3-D thermo-mechanical FE analysis to evaluate welding residual stress in austenitic stainless-steel pipes. He then compared the results of FE analysis and Ultrasonic method to determine the accuracy of FE analysis. [7,8]

2.3.1. Contact method

The contact method is done by L_{CR} method. Tang et al in their experiment used a special longitudinal bulk wave mode called the L_{CR} method, mainly propagating beneath the surface at a certain depth [12]. When a longitudinal wave passes through an interface between two materials, there is an incident angle that makes the angle of refraction for the wave 90.

This is known as the first critical angle which is calculated 28 from the Snell's law when the wave moves from PMMA wedge to the steel.

Palanichamy et al used in their experiment the contact measurement device, includes an ultrasonic box, computer and time of flight (TOF) measuring element. Also, a measuring table is needed to move TOF measuring element accurately and with enough stability. The ultrasonic box is a 100 MHz ultrasonic testing device to determine residual stress. [13]

Egle and Bray in their experiment derived the relation between measured travel-time change of LCR wave and the corresponding uniaxial stress [14].

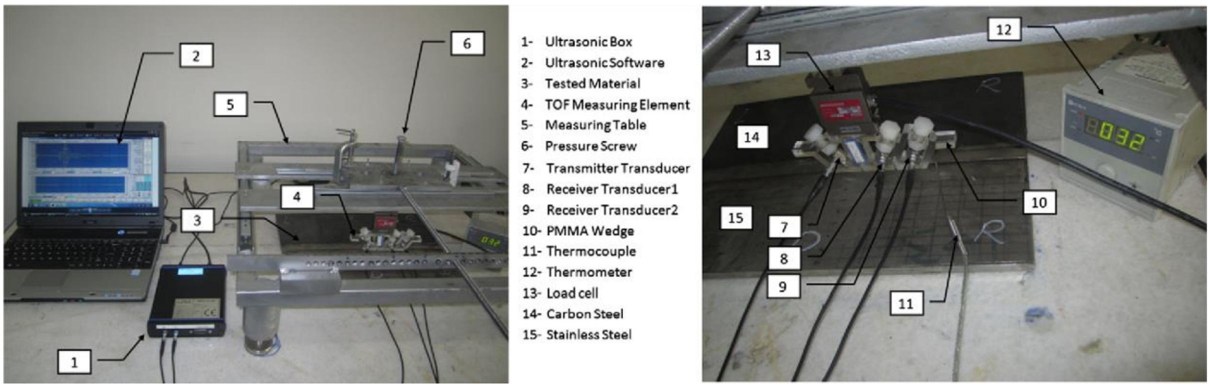


Fig 5. Experimental setup of contact method

2.3.2. Immersion method

Two 220 mm length pipes from stainless steel (TP304) and carbon steel (A106) are welded where their thickness and diameter is 8 mm and 220 mm respectively. The root pass is welded by gas tungsten arc welding (GTAW) process while shielded metal arc welding (SMAW) is used to accomplish the other passes. The automated measuring table makes it possible to move the TOF measuring element with 1 m resolution and 3D measuring of residual stresses. TOF measuring element includes two 2 MHz immersion transducers assembled on an integrated wedge to measure the time of flight. Because of welding deformations in the surface of the tested material, the gap between transducers and tested surface is changed when the TOF measuring element moves. To eliminate effect of these changes on the measured TOF, an adjusting transducer is used to keep the distance constant.

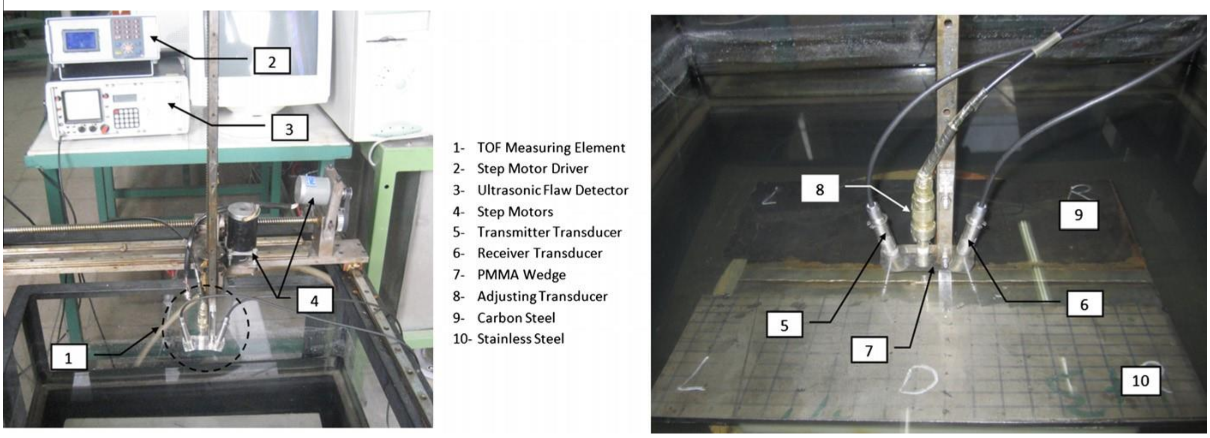


Fig 6. Experimental setup of Immersion method

Quozom et al concluded from their experiment that the disagreement between these methods and the FEA method is mainly noticeable in the Heat Affected Zone (HAZ) [15]. The contact measurement is more time-consuming than immersion inspection in case of the dissimilar welded pipes while the situation is reversed about the dissimilar welded plates. Using some of cost-consuming equipment (like load cell, temperature monitoring system and second receiver probe) are not necessary in the immersion measurements because the environmental effects are more controllable in comparison with the contact inspection.

2.4. Hole drilling method

The hole-drilling method is a standard technique for measuring residual stresses as described in detail in ASTM E837 [12]. The stress measurements will be made in three points at outer surface of the pipes. These points are made in such a way that point A is located on the weld centre line, point B 40 mm from the weld centre line in the stainless-steel side and point C 35 mm in the carbon steel side, as shown in Fig. 11. Strain gages of type FRS-2-1 will be mounted on the pipe at selected points to measure the released strains after drilling a hole. With the help of the strain value, stress can be found since these are inversely proportional. The hole is made by using a very high-speed drill of RS-200 type. [16]

Fig. 8. Experimental setup of Hole drilling method

Akbari et al used the finite element techniques to analyse the thermo-mechanical behaviour and residual stresses in dissimilar butt-welded pipes. The residual stresses at the surface of some weld specimens were measured experimentally by using the hole-drilling method. The results of the finite element analysis were compared with experimentally measured data to determine the accuracy of the finite element modelling. Based on this study, a modelling procedure with reasonable accuracy was developed.

2.5. Finite Element method

The finite element method is done by using meshing and with the help of software such as ANSYS and HYPERMESH as explained in the previous cases.

Javadi et al in their experiment to accurately capture the temperature fields and the residual stresses in the welded pipe, a 3-D finite element model was developed. The thermo-metallurgical behaviour of the weldment during welding process is simulated using uncoupled formulation, because the dimensional changes in welding are negligible and the mechanical work done is insignificant compared to the thermal energy from the welding arc. [17]

The FEM modelling used adopts the technique of element birth and death to simulate the deposit filling during the welding. This technique activates or deactivates elements during the analysis, by multiplying their stiffness using a severe reduction factor. Similarly, mass, damping, specific heat, and other such effects were set to zero for deactivated elements.

Lindgren used the technique of element birth and death to simulate the welding process. By the comparison with the experimental measurements, it has been shown that the proposed computational procedure is an effective method for predicting the welding residual stresses. [18]

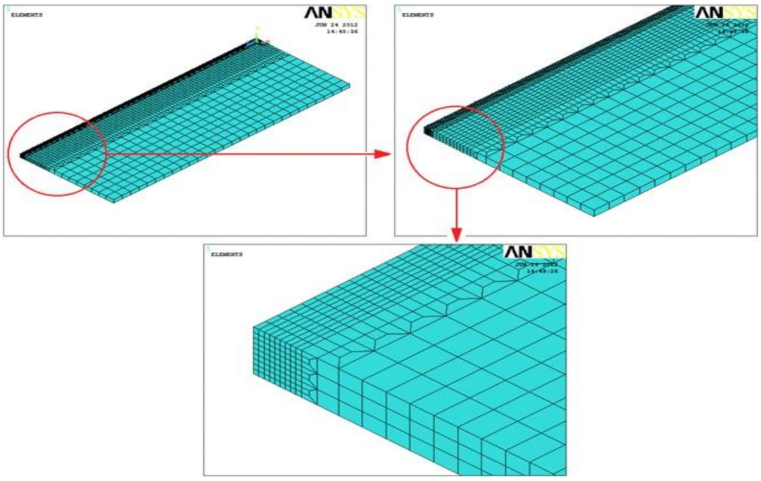


Fig 4. Meshing pattern in ANSYS

Numerical simulation of welding residual stresses needs to accurately consider the interactions between heat transfer, metallurgical transformations and mechanical fields. The phenomena involved in the heat input such as arc, material interactions, as well as, fluid dynamics in the weld pool are not precisely described. From the thermo-mechanical point of view, the heat input can be a volumetric or surface energy distribution and the fluid flow effect, which leads to homogenized temperature in the molten area, and can be simply considered by increasing the thermal conductivity over the melting temperature.

Heinze et al in their experiment performed the numerical simulation with the commercial FEA-code SYSWELD. The numerical calculation is based on 3-D mesh geometry which is used for thermal and mechanical calculation. To reduce the computation time, the mesh is gradually coarsened on the outer regions. The full model consisted of 1,06,000 linear elements and 1,17,000 nodes. [6]

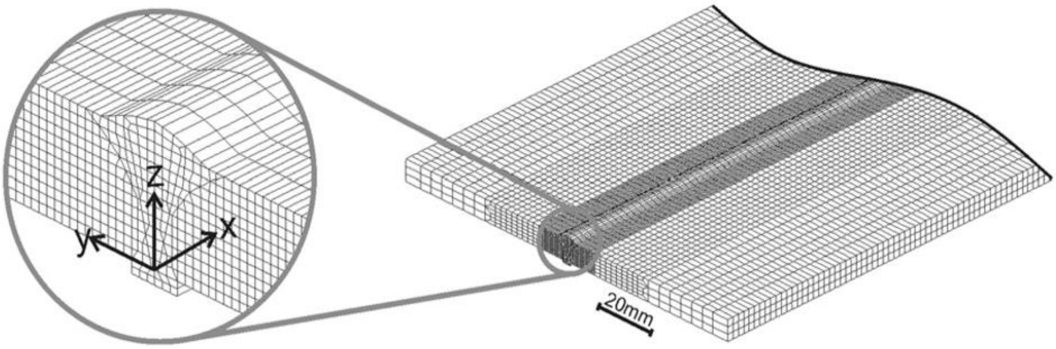


Fig 3. Detailed view of meshing in SYSWELD

The developed model is successfully applied to investigate the influence of non-uniform martensitic transformation.

3. RESULT AND DISCUSSION

Welding is a metal joining process used to join two pieces of similar or dissimilar metals such as pipes and plates.

The literature review provides information on different methods both destructive and non-destructive methods used for determination of residual stress.

The effect of non-uniform martensitic transformation is studied by using X-ray diffraction method and numerical method and the results of both the methods are compared. The experiment proves that the results of both the methods are in agreement with each other.

In austenitic steel plates, Ultrasonic method and FE method are used to determine the residual stresses. Then the results of both the methods are compared to determine the accuracy of FE method.

Then the same experiment is performed by using contact ultrasonic method and immersion ultrasonic method. Immersion method is better in some aspects as there is no problem of environmental factors as there in contact ultrasonic method.

A Destructive method called Hole drilling method is also used to measure residual stress. This gives a more agreeable result when compared with finite element method.

4. CONCLUSION

From the above review, two conclusions can be obtained. First is that if the material is not used again, then the hole drilling method is preferred because it gives an accurate result since the stress is measured with the help of the amount of strain that is received when a hole is drilled. Second is that if the material need not to be used again, then ultrasonic method can be used since it is one of the widely used techniques and it gives an accurate result based on the time of flight of the ultrasonic wave within the material.

5. REFERENCES

[1] Olabi AG, Hashmi MSJ. The effect of post-weld heat-treatment on mechanical- properties and residual-stresses mapping in welded structural steel. J Mater Process Technol 1995;55:117–22.

[2] Peng-Hsiang C, Tso-Liang T. Numerical and experimental investigations on the residual stresses of the butt-welded joints. Computational Materials Science 2004;29:511–22.

[3] Rossini NS, Dassisti M, Benyounis KY, Olabi AG. Methods of measuring residual stresses in components. J Mater Des 2012;35:572–88.

[4] Palanichamy P, Joseph A, Jayakumar T. Ultrasonic velocity measurements for estimation of grain size in austenitic stainless steel. NDT E Int 1995;28:179–85.

[5] JSMS committee on X-ray study on mechanical behaviour of materials, “Standard method for X-ray stress measurement - steel,” JSMS-SD-5-02 (2002) pp. 5-16

[6] C. Heinze, C. Schwenk, M. Rethmeier, The effect of tack welding on numerically calculated welding-induced distortion, J. Mater. Process. Technol. 212 (1) (2012) 308–314.

[7] Thompson RB, Lu WY, Clark Jr. AV. Handbook of measurement of residual stress. In: Lu J, James M, Roy G, editors. Society for Experimental Stress Analysis. Bethel; 1996, p. 149–78.

[8] Schneider E. Structural and residual stress analysis by non-destructive methods. In: Hauk V, editor. Amsterdam: Elsevier; 1997, p. 522–63.

[9] Bray DE, Tang W. Subsurface stress evaluation in steel plates and bars with the LCR ultrasonic wave. Nucl Eng Des 2001;207:231–40.

[10] Lindgren LE. Finite element modelling and simulation of welding. Part 2: Improved material modelling. J Thermal Stress 2001;24:195–231.

[11] Zhu XK, Chao YJ. Numerical simulation of transient temperature and residual stresses in friction stir welding of 304L stainless steel. J Mater Process Technol 2004;146:263–72.

[12] Tang W, Bray DE. Stress and yielding studies using critically refracted longitudinal waves. NDE engineering codes and standards and material characterization, Montreal: ASME pressure vessels piping conference 1996;322:41–8.

[13] Palanichamy P, Vasudevan M, Jayakumar T. Measurement of residual stresses in austenitic stainless steel weld joints using ultrasonic technique. Sci Technol Weld Joining 2009;14:166–71.

[14] Egle DM, Bray DE. Measurement of acoustoelastic and third-order elastic constants for rail steel. J Acoust Soc Am 1976;60:741–4.

[15] Qozam H, Chaki S, Bourse G, Robin C, Walaszek H, Bouteille P. Microstructure effect on the LCR elastic wave for welding residual stress measurement. Exp Mech 2010;50:179–85.

[16] ASTM E837. Standard test method for determining residual stress by the hole drilling strain gage method. 1995; 3(1).

[17] Javadi Y, Akhlaghi M, Najafabadi MA. Using finite element and ultrasonic method to evaluate welding longitudinal residual stress through the thickness in austenitic stainless steel plates. J Mater Des 2013;45:628–42.

[18] Lindgren LE. Finite element modelling and simulation of welding. Part 1: Increased complexity. J Thermal Stress 2001;24:141–92.