REVIEW ON DISTORTION OVER WELDED STRUCTURES

George-Ciprian Iatan  
“Dunarea de Jos” University of Galati, 
Faculty of Naval Architecture, Galati, Domneasca Street, No. 47, 800008, Romania,  
E-mail: ciprianiatan@yahoo.com

Elisabeta Burlacu  
“Dunarea de Jos” University of Galati, 
Faculty of Naval Architecture, Galati, Domneasca Street, No. 47, 800008, Romania,  
E-mail: burlacu.elisabeta@gmail.com

ABSTRACT

While welding started to be used on large scale in engineering, distortion has become a stringent problem for industry, mostly for shipyards. This paper aims to bring together the result of large amount of research on distortion and mitigation techniques, in order to support further practical research on topic. Phenomena was explained in detail, such as mostly used treatments for reducing distortion. In addition to this, inherent strain theory was presented for offering a starting point to those which shall perform thermal analysis in welded structures.

Keywords: Welding distortion, thermal treatment, inherent strain.

1. INTRODUCTION

Since welding technology started to be extensively used in industries for joining subassemblies of ships, automobiles, aerospace and civil engineering, lot of studies have been done on it’s effects on structures.

Although welding is a process of grate versatility, it reveals also inconveniences such as high strain and stress in the structures, which generate distortion of welded elements. This aspect has grate importance in shipbuilding industry, due to it’s high cost for countermeasure, estimated by Navy Joining Centre (EEUU) to almost 25% of total expenditure on assembly work. [1].

According to The Welding Institute of UK, most of shrinkage are resulted by the contraction of welded area, on cooling. Furthermore, non-uniform contraction shall induce angular change, mostly on T joints. For thin plates, long range compressive stresses can produce elastic buckling.[2]

Higher residual stress occur in structures when small distortion or even no distortion appear, after welding has cooled.[3]

Ship Structure Committee elaborated in late 60’ a large research over one of the biggest disadvantage subsequent to welding, namely distortion, entitled “Flame straightening and it’s effect on base metal properties” [4]. Authors highlighted flame straightening techniques and plastic strain induced, for different nature of distortion. Also, material degradation for exceeding “dull red” heating of high-strength low alloy steels is largely analysed in connection with cooling methods.

In order to establish new ways for minimizing the effect of distortion, each type must be analysed and understood.

Essentially, welded structures may encounter six types of deformation, namely: longitudinal shrinkage, transverse shrinkage, longitudinal bending, angular distortion, rotational distortion and buckling distortion.[5] Their particularities are represented in Fig 1.
The last two occur as a result of the first four type, known in the literature as inherent deformations. Also, deformations are grouped as: in plane deformation for longitudinal shrinkage, transversal shrinkage and rotational distortion, but also as out of plane deformation, for: longitudinal bending, angular distortion and buckling distortion. [6]

Establishing if distortion is caused by bending or buckling is mandatory for thin plate welded structures. Main differences consist in the fact that buckling has multiple stable deformed shapes, it distorts the structure with a greater amount and much faster than bending. [7]

2. INFLUENCE FACTORS OVER DISTORTION PHENOMENON [2]

Distortion would be almost avoided if a structure would be symmetrically heated and cooled. Though through no uniform stresses exceeding steel yield stress, permanent distortion occurs. There are five main parameters that influences distortion phenomenon, associated with welding particularities.

Parent material properties, such as specific heat and coefficient of thermal expansion, due to its influence on expansion of metal upon heating. An important aspect on topic, for FEA analysis performed especially on NASTRAN software, is to use mean coefficient of thermal expansion, instead of true coefficient. [8]

Restraint method considered for reducing the degree of freedom of structures before welding is important in distortion occurring for its risk of producing cracks in weld metal due to residual stress involved. In order to use properly strong-back restrainings, internal shipyard standards and procedures shall be respected.

Proper joint design shall decrease the degree of distortion due to symmetrical heat input through the plate.

Welding preparation consisting in proper gap and angle for each welding type produces uniform shrinkage. Exceeding these parameters shall result in adding increased amount of weld metal with direct negative effect on distortion.

Welding procedure introduces welding sequence and technique and has to be strictly followed due to its effects over quality and productivity.

3. INHERENT STRAIN THEORY

Inherent strain is a method used for estimating welding distortion by performing FEM elastic analyse instead of elasto-plastic one, which is burdensome and involves high computing time for large structures [9] and was introduced by Y. Ueda[10].

Considering a body in three different states, namely: standard state without internal stress or external forces, under residual stress and released from residual stress by dividing in small pieces[11], Murakawa described strain states by small deformation theory:[12]

$$\varepsilon = \frac{\delta_{r} - \delta_{i}}{\delta_{i}} \delta_{i}$$
$$\varepsilon^{*} = \frac{\delta_{r}^{*} - \delta_{i}^{*}}{\delta_{i}} \delta_{i}$$
$$\varepsilon^{e} = \frac{\delta_{r}^{e} - \delta_{r}^{e}}{\delta_{i}} \delta_{i}$$

Considering $\delta_{r}$, $\delta_{r}^{e}$, $\delta_{r}^{e}$, as being a distance between two nodes in standard state, under residual stress and released from
stress, total strain of the welded element $\varepsilon$, can be defined as a sum of elastic strain $\varepsilon^e$, and inherent strain $\varepsilon^*$.\[^{[5]}\] Inherent strain consists in thermal strain $\varepsilon^{th}$, plastic strain $\varepsilon^p$, creep strain $\varepsilon^{cr}$ and phase transformation $\varepsilon^{ph}$.\[^{[5]],[13]}\] As some authors suggest, for low-carbon steel because of small dilatation, $\varepsilon^{cr}$ and $\varepsilon^{ph}$ can be ignored.\[^{[9-5]}\] Also, thermal strain is assumed to disappear when material temperature returns to ambient temperature, case when inherent strain $\varepsilon^*$ becomes equal with plastic strain $\varepsilon^p$.\[^{[9]}\]

4. TECHNIQUES FOR REMOVING DISTORTION AFTER WELDING

Distortion occurring after welding can be reduced by considering several procedures and preparation before fixing components with weld material. Although every effort is being made to avoid distortion, it is not always possible to eliminate the phenomenon. In order to decrease distortion to acceptable limits, several remedial techniques were developed.

4.1 Mechanical techniques

Though mechanical approach is not used on large scale through cracking and surface damage risks, there are few techniques that proved good results in straightening.

Most used in case of angular distortion or dishing is hydraulic press that produce plastic deformation to correct distortion. Industrial approach can use cambering machines to remove distortion by successive series of pressing. Hammering directly on steel plates is forbidden by almost all shipyards internal procedures.

Unconventional post-weld methods were proposed from early 60’s by Kurkin[14] as mitigation techniques, but has received little attention. After 2010, more preoccupation was enrolled for rolling methods after welding by Coules at al. [15].

4.2 Thermal techniques

As being used for many years all over around the world, thermal techniques are most used approach to overcome distortion. The principle is to introduce high local thermal stress so that on cooling to generate plastic deformation which pulls the steel closer to it’s original shape. Technique introduces stresses that affects the material between proportionality limit and yield limit, as it is shown in Fig. 2. [2],[3]

![Fig. 2 Thermal straightening zone on stress-strain diagram](image)

It is important to maintain straightening between the two points, where material although still has an elastic behaviour, it reports residual stress and small distortion.\[^{[16]}\]

Thermal treatment for reducing distortion consist in: line heating, wedge-shaped heating or spot techniques. Spot heating is used for reducing buckling distortion, wedge for increasing or decreasing camber of plates or stiffeners and line heating usually for correcting localized distortion.\[^{[2]}\] Treatment is being made with torches having single or multiple nozzle.

Straightening procedure is based on particular techniques, fluctuating over production stage of the ship. Thermal treatment shall start in an area, only after welding was finished in the sector and adjacent areas. It starts from the bottom of the ship to the top side and from middle to the sides, firstly for decks and then for the walls between them, as it is shown in Fig. 3. [17]
Another distortion reduction technique, proposed by Edison Welding Institute, is transient thermal tensioning. It fits for flux core arc welding at panel line workshop and consists in performing symmetrical heating together with welding process by using propane torches.[1]

As welding is a process largely used in marine industry, every shipyard faced distortion problem. In order to reduce it’s impact, lot of researches has been done and some patents were developed on topic by Japanese, Chinese and Russian researchers. Most of them consist in heating adjacent areas of welding while cooling welding, by using or not restraining, during or after joining plates.[18]

5. **VARD STUDY ON DISTORTION ON PRODUCTION STAGE[19]**

As being an important player in Romanian shipbuilding, Vard Braila developed internal studies aiming to identify which are the sources of distortion by involving all departments of the company that are using welding process in their activity. The study was made in 2017 by using Ishikawa method for questioning shipyard personnel on topic.

Points that have been found in need for improving were: improper technological sequences, welding throat thickness and quality level from previous stage.

In order to solve there challenges, Vard Braila successfully performed training programs for welders. Also, more straightening teams were trained and introduced in production stage at erection department. In addition, Quality Control department increased patrolling inspections and has been involved in surveying optimized techniques.

The result was that quality level of final product dramatically improved.

6. **CONCLUDING REMARKS AND FURTHER DEVELOPMENTS**

In this review paper we proposed to analyse the problem of distortion after welding, in order to support further studies on the topic. The phenomenon was presented starting from what causes it to it’s remedial solutions, by studying a large amount of technical papers. Considering world industrial experience in dealing distortion after welding, several proven techniques for remedial were presented in the paper. Furthermore, international patents and studies were taken into consideration aiming to suggest unconventional approaches for distortion remedial.

Starting from this general knowledge, distortion of a stiffened welded panel is going to be analysed and a FEM model shall be realized, using inherent strain theory. Also, comparisons between elastic FEM analyse and thermal elasto-plastic FEM analyse shall be realized. Obtained results from simulating thermal treatment with FEM, are going to be compared to experimental model and presented in future papers.
Acknowledgements

The research was supported by VARD Braila Shipyard, whom we are greatly thankful for granting their support.

FEM simulations are directly supported by PhD. Eng. Leonard Domnisoru, professor at Naval Architecture Faculty, in “Dunarea de Jos” University of Galati, whom we are grateful also.

REFERENCES

[1]. Souto, J., Ares, E., Alegro, P. “Procedure in reduction of distortion in welding process by high temperature thermal transient tensioning”, MESIC 2015, Procedia Engineering 132, p. 732-739.

[2]. www.twiglobal.com

[3]. BOC – The Linde Group, “Fundamentals of flame straightening”.

[4]. Ship Structure Committee, “Flame straightening and its effect on base metal properties”, 198, August 1969.

[5]. Ghanadi, M. “Managing distortion in welded structures using FEM”, Master of Science Thesis in Lightweight Structures, Stockholm 2013.

[6]. Liang, W., Deng, D., “Influences of heat input, welding sequence and curved stiffened panel”, Advances in Engineering Software, V.115, 2018, p. 439-451.

[7]. Asle Zaeem, M., Nami, R., Kadivas, M.H., “Prediction of welding buckling distortion in a thin wall aluminium T joint”, Computational Materials Science, V 38, 2007, p. 588-594.

[8]. ASM International “Thermal Properties of Metals”, 2002.

[9]. Gu, Y., et al. “Welding distortion prediction based on local displacement in the weld plastic zone”, International Institute of Welding 2017.

[10]. Ueda, Y., Fukuda, K., Nakacho, K., “A new measuring method of residual stresses with the aid of finite element method and reliability of estimated values”, Transaction of JWRI 1975-4(2) p. 123-131.

[11]. Saenz, A. et al., “Analysis and prediction of welding distortion in complex structures using elastic FEM”, Ship Science and Technology, V6, Cartagena Columbia 2012, p. 35-42.

[12]. Deng, D., Murakawa, H., Liang, W. “Welding computation methods applied in mechanical engineering”, 2007, 196,4613-4627.

[13]. Lei Xiu et al., “Welding distortion prediction of CFETR vacuum vessel by inherent strain theory”, Fusion Engineering and Design 2017, 121, p. 43-49.

[14]. Kurkin, “The relief of residual welding stresses in titanium alloy sheet structures”, Machines and Tooling, V33, 1962 USSR.

[15]. “High pressure rolling of low carbon steel weld seams”, Sci Weld Join., 2013, p. 73-90.

[16]. Faur, N., Barsaneanu, P. “Material Mechanins”, 2011.

[17]. VARD Braila, “Yard internal straightening procedure”, 2013.

[18]. Tsai, C., Park, C., Cheng, W., “Welding distortion of a thin plate panel structure”, Hyundai Industrial Research Institute of Korea 1999.

[19]. VARD Braila “Yard internal study on distortion”, 2017.

Paper received on November 10th, 2019.
