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REVIEW ON THE EFFECTS OF DISTORTION ON WELDED STRUCTURES

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ABSTRACT

Since welding started to be used on a large-scale basis in engineering, distortion has become a stringent problem for the industry, mostly for shipyards. This paper aims at bringing together the result of large amount of research on distortion and mitigation techniques, in order to support further practical research on the topic. Phenomena, such as mostly used treatments for reducing distortion were explained in detail. In addition to this, inherent strain theory was presented for offering a starting point to those who 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, aircraft and in civil engineering, lots of studies have been performed on its effects on structures.

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

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

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

In the late 60s, The Ship Structure Committee carried out a large research over one of the biggest disadvantages that occur subsequent to welding, namely distortion, entitled "Flame straightening and its effect on base metal properties" [4]. Authors highlighted flame straightening techniques and induced plastic strain, for different types of distortion. Also, material degradation for exceeding "dull red" heating of high-strength low alloy steels was largely analysed in connection with the cooling methods.

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

Essentially, there are six types of deformation that one may encounter in welded structures, namely: longitudinal shrinkage, transverse shrinkage, longitudinal bending, angular distortion, rotational distortion and buckling distortion.[5] Their particularities are represented in Fig 1.

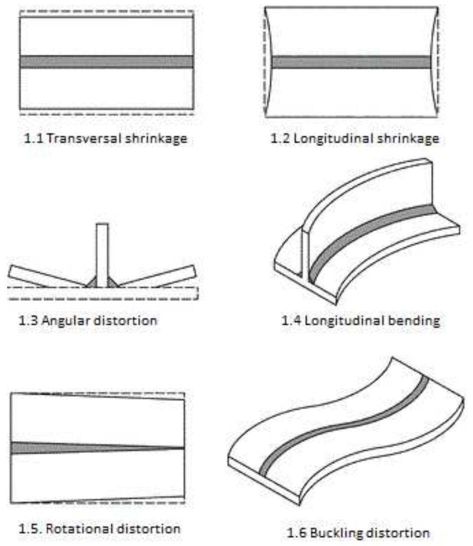

Fig. 1 Types of distortion

The last two occur as a result of the first four types, 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 to a larger extent and much faster than bending. [7]

2. INFLUENCE FACTORS ON THE DISTORTION PHEMOMENON [2]

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

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

The restraint method, considered for reducing the degree of freedom of structures before welding, is important in establishing the distortion that may occur due to its risk of producing cracks in the welded metal due to the residual stress involved. In order to properly use strong-back restrainings, internal shipyard standards and procedures must be complied with.

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

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

The welding procedure introduces the welding sequence and technique and has to be strictly followed due to its effects on quality and productivity.

3. THE INHERENT STRAIN THEORY

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

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

$$\varepsilon = (\delta_r - \delta_i)/\delta_i$$

$$\varepsilon^* = (\delta_{r*} - \delta_i)/\delta_i$$

$$\varepsilon^e = (\delta_r - \delta_{r*})/\delta_i$$

Considering δ_i, δ_r,δ_{r*} as being a distance between two nodes in standard state, under residual stress and released from stress, the total strain of the welded element ε, can be defined as a sum of the elastic strain ε^e, and the inherent strain ε^*.[5]

Inherent strain consists of thermal strain ε_{th}, plastic strain ε_p, creep strain ε_{cr} and phase transformation ε_{ph}.[5],[13]. As some authors suggest, for low-carbon steel, because of small dilatation, ε_{cr} and ε_{ph} can be ignored.[9-5] Also, thermal strain is assumed to disappear when material temperature returns to ambient temperature, case in which inherent strain ε^* becomes equal to plastic strain ε_p. [9]

4. TECHNIQUES FOR REMOVING DISTORTION AFTER WELDING

The distortion occurring after welding can be reduced by considering several procedures and some preparation before fixing components with welded 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 the mechanical approach is not used on a large scale due to the risk of cracking and surface damage, there are a few techniques that proved to have (sugestie: showed good results) good results in straightening.

Most used in the case of angular distortion or dishing is the hydraulic press that produces plastic deformation to correct distortion. The 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-welding methods were proposed from the early 60s by Kurkin[14] as mitigation techniques, but they have received little attention. After 2010, Coules at al. showed more interest in usingrolling methods after welding [15].

4.2 Thermal techniques

Being used for many years all around the world, thermal techniques are the most used approach to overcome distortion. The principle is to introduce high local thermal stress so that, when cooling, it generates plastic deformation, which pulls the steel closer to its original shape. The technique introduces stresses that affect the material between the proportionality limit and the yield limit, as shown in Fig. 2. [2],[3]

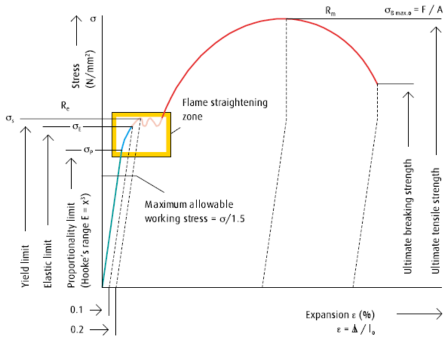

Fig. 2 Thermal straightening zone on stress-strain diagram

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

The thermal treatment for reducing distortion consists of: 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 applied with torches having single or multiple nozzles.

The straightening procedure is based on particular techniques, fluctuating during the production stage of the ship. The thermal treatment shall start in an area, only after the welding was finished in the sector and in the 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 shown in Fig. 3. [17]

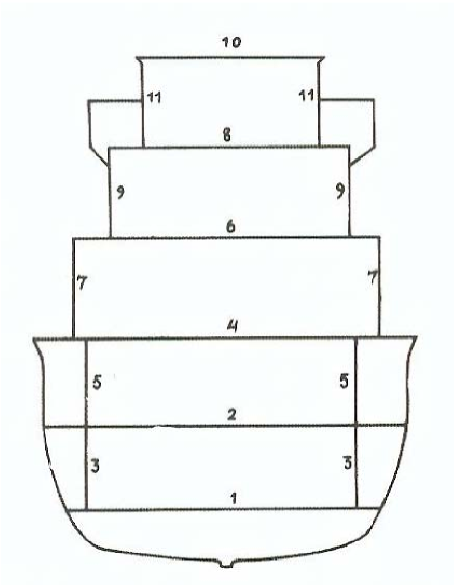

Fig. 3 Flame straightening priority in shipyard

Another distortion reduction technique, proposed by the Edison Welding Institute, is transient thermal tensioning. It is suitable for flux core arc welding at panel line workshop and consists in performing symmetrical heating together with the welding process by using propane torches.[1]

As welding is a process which is largely used in the marine industry, every shipyard faces distortion problems. In order to reduce it`sits impact, a lot of research has been performed and some patents were developed on the 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 DURING THE PRODUCTION STAGE[19]

As being an important player in Romanian shipbuilding, Vard Brăila developed internal studies aiming at identifying which the sources of distortion are by involving all departments of the company that are using welding processes in their activity. The study was conducted in 2017 by using the Ishikawa method for questioning the shipyard personnel about the topic.

The points that have been found in need of improvement were: improper technological sequences, welding throat thickness and the quality level from the previous stage.

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

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

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 its remedial solutions, by studying a large amount of technical papers. Considering world industrial experience in dealing with distortion after welding, several proven remedial techniques were presented in the paper. Furthermore, international patents and studies were taken into consideration aiming at suggesting unconventional approaches to distortion remedial.

Starting from this general knowledge, the distortion of a stiffened welded panel is going to be analysed and a FEM model shall be drawn up, using the inherent strain theory. Also, comparisons between the elastic FEM analysis and the thermal elasto-plastic FEM analysis shall be carried out. The obtained results from simulating thermal treatment with FEM, are going to be compared to the experimental model and presented in future papers.

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