ISSN 2229-5518

Dimensional Accuracy Control in Shipbuilding

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Abstract- The main purpose of this paper is to explore how to reduce the errors in final scantlings of the whole ship's hull which could be achieved by controlling and minimizing the errors in dimensions in each single plate used and each production process which the materials are submitted to like cutting, forming and welding which are affected by a lot of errors due to many factors. Those errors and their remedies are to be investigated using computer aided simulations.

Index Terms— Accuracy Control Model, Forming Simulation, shipbuilding, Welding Simulation

1 Introduction

Ship's hull design must achieve a set of performance requirements concerning speed and fuel consumption. So, using curved parts becomes a must to improve hydrodynamic flow around the ship. Curved plates cover more than 50–80% of the whole shape of the hull. In particular, it is noticed that, among the hull parts, the bow and the stern are made of plates of complex shape such as doubly curved plates, and precise and efficient fabrication of such curved parts is very critical not only in the quality and performance of the completed ship but also in the efficiency of the manufacturing process. [1]

Nowadays shipbuilding market becomes very competitive, shipyards try to apply new techniques to help reducing the shipbuilding process time, and cost by reducing the amount of errors done to avoid redoing the work, wasting effort and time. [1]. Such errors appear due to distortion in the construction processes such as ignoring cutting kerf (cutting tool thickness) and machining tolerance during the nesting process [2], the thermal stress in the heat affected zone (HAZ) during heat cutting [2], springback that occurs after bending tool is released causing change in the dimensions and angles of the workpiece [4], The difficulty of acquiring the initial flat dimensions of the curved drawing due to the complexity of ship's parts as they are multi-curved [12], and thermal stresses caused from the welding process.[13]

In this paper the inaccuracy causes are discussed and solutions were represented in order to eliminate all unwanted deformations. Also, a case study was done to test the effects of such solutions and how will they improve the ship building output.

2 Application of accuracy control model

This model is based on collected data and various simulations carried out on the shipbuilding processes to optimize the accuracy results in order to achieve high technical and cost-efficient shipyard.

1. Determination of the initial dimensions of the plate by applying the equations to all the curved parts using a software such as (SolidWorks).

$$BA = A\left(\frac{\pi}{180}\right)(R + (K \times T)) \quad (1)$$

$$BD = 2\,(R + T)\tan\frac{A}{2} - BA \quad (2)$$

$$OSSB = (R + T)\tan\frac{A}{2} \quad (3)$$

$$K = \frac{t}{T} \quad (4)$$

$Initial\ length = Leg\ 1\ (B1) + BA + Leg\ 2\ (B2)$ [6]

Lf = flat length of the sheet (initial length)
BA = bend allowance (mm)
BD = bend deduction (mm)
R = inside bend radius (mm)
K = K-Factor
T = material thickness (mm)
t = distance from inside face to the neutral line (mm)
A = bend complimentary angle in degrees (degree)
B = leg length (mm) C = flange length (mm)
OSSB = outside set back (mm)
Apex = end of the leg and start of the bent (mm). [6]

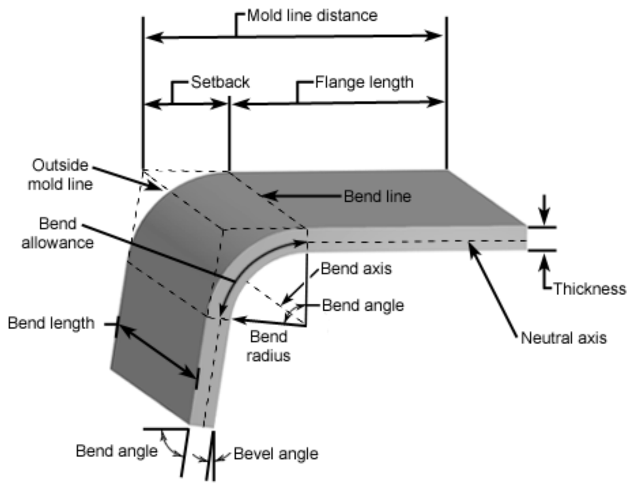

Fig. 1: Bending parameters

2. Parallelly nest all parts in the same group using multi-sheet nesting software that nests all the steel sheets with same thickness at the same time producing optimum results
3. During nesting consider the cutting machine parameters (Kerf and tolerance)
4. Using the following springback equations to calculate the initial bending radius, thickness, angle, and bending force that should be applied to gain the designed parameters. [7]

$$SB\ Variable = \frac{R1*\sigma}{1000*E*T} \quad (5)$$

$$SB = (4*SBV^4) - (3*SBV) + 1 \quad (6)$$

$$R2 = \frac{R1}{SB} \quad (7)$$

$$A2 = \frac{(R1+(K*T))*A1}{R2+(K*T)} \quad (8)$$

$$SB\ Factor = \frac{A2}{A1} \quad (9)$$

$$K = \frac{t}{T} \quad (10)$$

Where:
SB: springback
R1: initial bend radius (mm)
R2: final bend radius (mm)
A1: initial bend internal angle (degree)
A2: final bend internal angle (degree)
T: metal sheet thickness (mm)
K: K-Factor, which is t / T
σ: yield strength (GPa)
E: modulus of elasticity. (MPa) [7]

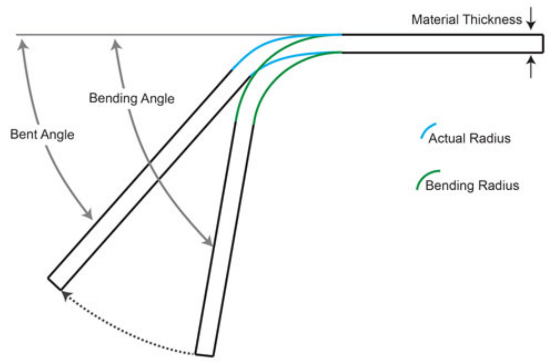

Fig. 2: Spring back bending and bent angle and radius

5. Use water jet cutting Computer Numerical Control (CNC) machine.
6. Measure the resulted cut parts periodically and compare it to the technical drawings.
7. Send the measured data to the technical office to be processed and then produce final charts to monitor the process quality and interfere when needed. [9]
8. During bending process either using hydraulic pressing or rolling the angle and radius should be measured frequently and compared with the calculated force.
9. After the tool is released another measurement should be taken to ensure that the final dimensions of the formed workpiece fit the drawings.
10. Measurements and monitoring results must be exported to the technical office to be processed and produce final charts to monitor the process and interfere in case of abnormality. [9]
11. Precisely calculate all welding parameters needed for each thickness weldment such as voltage, current intensity, rod thickness, rod material, number of passes, feed rate, pre-welding edge preparation, welding gap, and welding type in order to avoid extra unnecessary temperature added to the metal.
12. Workpieces must be fixed correctly according to its' welding position and place by using suitable clamping.
13. Apply frequent cooling using a cupper serpentine around the clamping and workpiece to absorb the welding heat to avoid heat stresses.
14. Measure the final dimensions of the two welded parts and compare it with the technical drawings
15. Transfer the measured data to the technical office to be processed and produce final charts to monitor the process and interfere when needed
16. Using all the data given, draw control charts to monitor and control the manufacturing results.

ISSN 2229-5518

3 Case study

A plate of mild steel "S355J2G3" of dimensions 6000 X 1000 X 10 mm was chosen to calculate the stresses and distortion due to forming and welding. Such design was chosen due to simplicity in design, its presence in all ships and the ability to acquire high quality simulation results.

The data sheet of the material is in ref [10] and [11].

To carry out the required calculations, the following software were used:

- Dassault SolidWorks©
- ANSYS© ICEM CFD workbench
- Simufact© Welding
- Simufact© Forming

The body is created using Dassault SolidWorks©

Mesh created using ANSYS© ICEM CFD

Mesh info:

Element types:

HEXA_B: 12500

QUAD_ 4: 6000

Total element: 18500

Total nodes: 15606

Forming simulation was carried out using Simufact© Forming while welding simulation was carried out using Simufact© Welding

3.1 Forming

The above-mentioned plate was bent to be a part of the bilge strake. The bending process characteristics are:

- Roller hydraulic press
- Steady motion nonuniform bending force (increasing force bending) fig. (3)
- Bending to 80° complimentary angle
- Bent radius 400 mm.

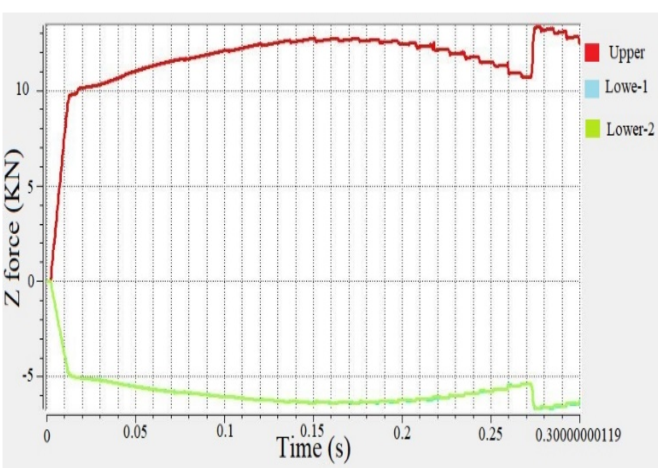

Fig. 3 Bending force to time plot during bending simulation

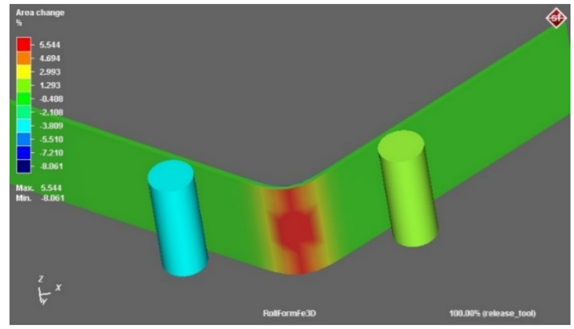

Fig. 4: Material tension due to bending

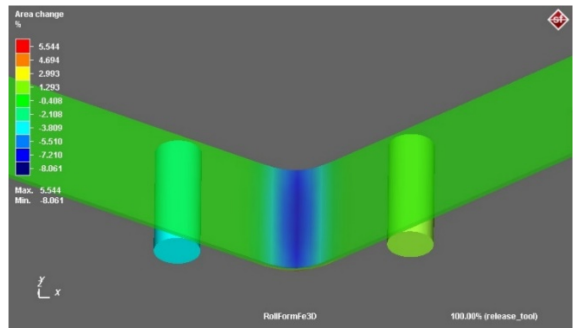

Fig. 5: Material compression due to bending

The study was performed in order to acquire the dimensions and instructions that should be given by the technical office to the manufacturing department in order to achieve the required final dimensions, and avoiding springback and acquiring the actual initial flat plate dimensions.

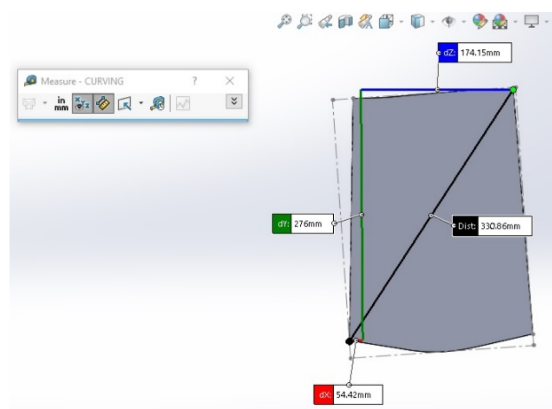

Fig. 6: Flattening and acquiring the initial dimensions using Solidworks© software

3.2 Forming test results:

When the bending process was simulated using "Simufact Bending" software simulating real live bending process and the plate then was flattened using "SolidWorks" 3D software the following results were found:

- Bending force right before tool release approximately equal to 47000 MPa
- The bending drum used should be of 387.2 mm radius
- The bending angle reach up to 82° 32' 10'' before tool release to achieve 80° after release
- The initial dimensions of the sheet are 6000 X 1000 X 10 mm (using full plate) to achieve the dimensions of:

B_1 = 2720.5 mm	B_2 = 2720.5 mm
A = 80°	R = 400 mm
T = 10 mm	t = 3.3 mm

3.3 Welding

The above-mentioned plate was welded to another similar plate in ship's hull and a 100 X 100 X10 mm section from each plate was studied using the following welding of characteristics:

- Arc welding
- 20 volts DC current of 90 Amps intensity
- Welding feed speed 5 mm/s
- Welding time 20 s and cooling time 10 s
- Simulation was held in 20^{o} C room temperature.

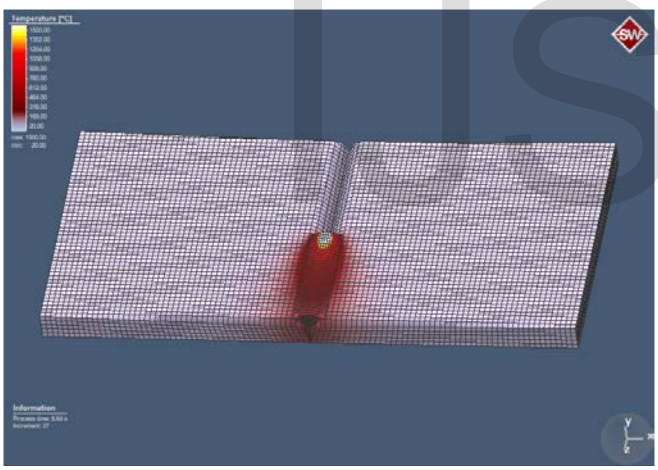

Fig. 7: Welding process simulation

The welding simulation process was done for the following conditions:

First condition: The plate under consideration has a free end fig. (11).

Second condition: The plate under consideration has a free end plus continuous water-cooling fig. (8).

Third condition: The plate under consideration is fixed using 100 KN clamping fixation,

Fourth condition: The plate under consideration is fixed using 100 KN clamping fixation with continuous water-cooling fig. (10).

3.4 Welding test results:

The obtained results of the Simufact welding software are presented in the charts fig. (16) and fig. (17):

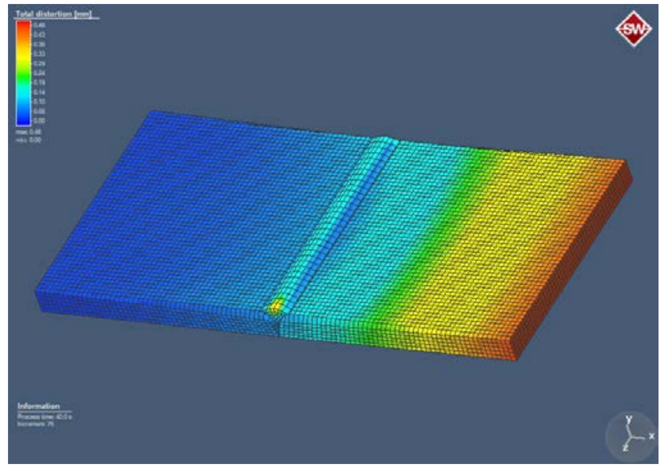

Fig. 8: Second condition total distortion After the workpiece was left to cool down

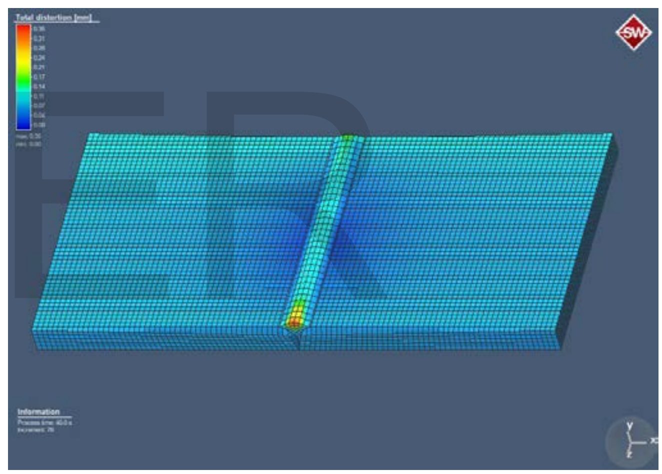

Fig. 9: Fourth condition Total distortion After the workpiece was left to cool down

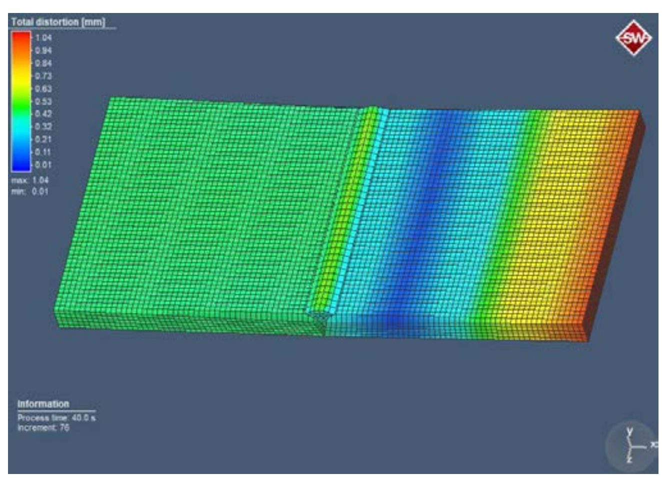

Fig. 10: First condition total distortion after leaving the workpiece to cool down

ISSN 2229-5518

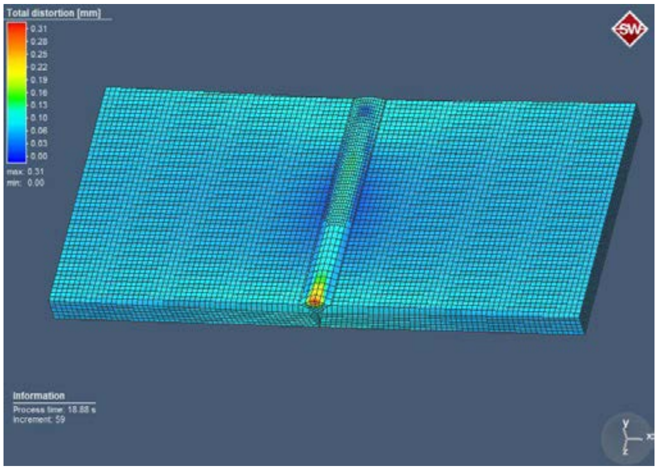

Fig. 11: First condition total distortion at the end of welding process

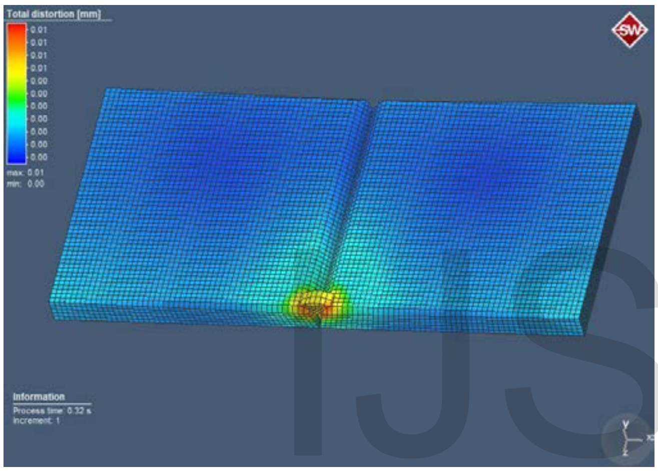

Fig. 12: Total distortion at the beginning of welding process

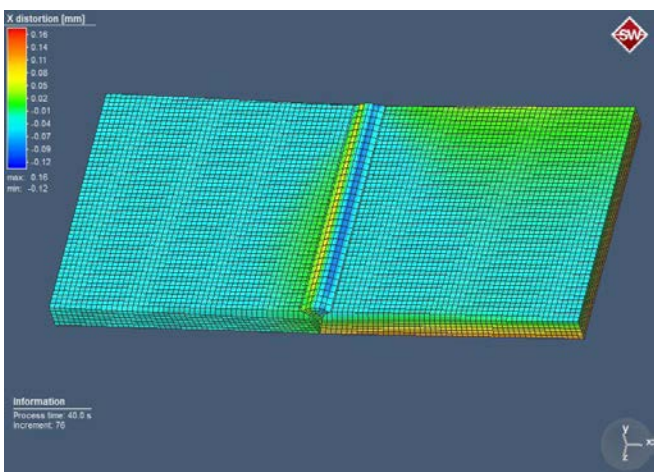

Fig. 13: First condition X-Axis after leaving the workpiece to cool down

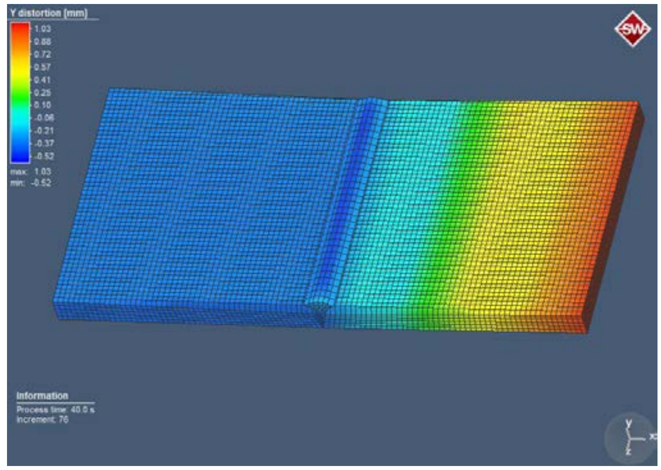

Fig. 14: First condition Y-Axis after leaving the workpiece to cool down

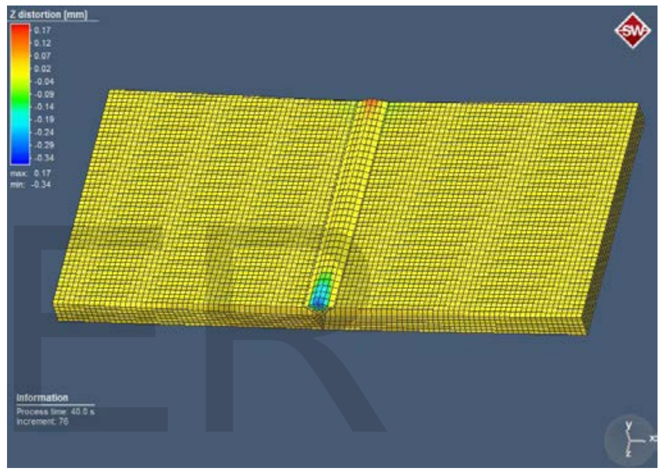

Fig. 15: First condition Z-Axis after leaving the workpiece to cool down

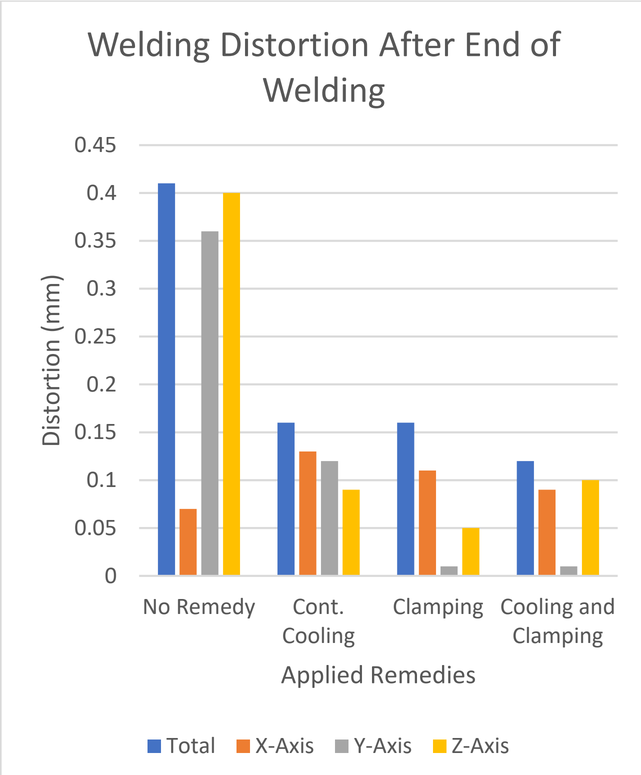

Fig. 16: Welding distortion values at the end of welding process

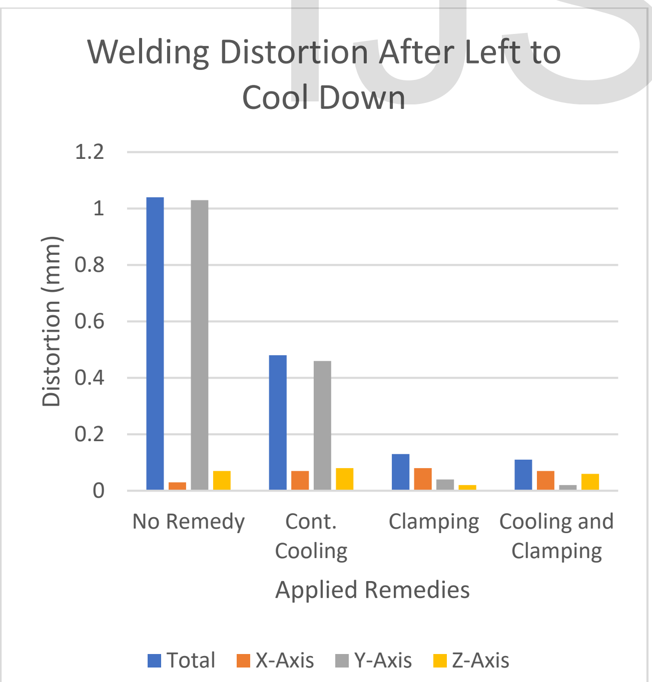

Fig. 17: Welding distortion values after the workpiece was left to cool down

4 CONCLUSIONS

The results of the forming simulation show that the if the springback was calculated before starting the forming process it could be compensated to achieve the required results that increase the accuracy of the bending process by about 3.2% preventing 547.103 MPa of effective stress.
Also, the initial dimensions could be accurately calculated using equations and software in order to achieve the demanded final scantlings.
By studying the results of the welding simulation process and remedies tried to achieve the minimum distortion shown in fig. (16) and fig. (17) the next were picked up:

- The distortion reaches its maximum after the metal was completely left to cool down to room temperature
- The continuous external cooling of the weldment during and after welding reduces the distortion of the welding of total approximately 54%, and specially distortion in X-axis which is reduced by approximately 36% which affects the assembly of the steel plate
- The fixation of the free plate using constant force during the welding reduces the distortion of the welding of total approximately 86%, and specially distortion in Z-axis which is reduced by approximately 71% which affects the built-up stresses in the ship's hull.
- Combining both remedies can reduce up to 89% from welding distortion.

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