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## Numerical modelling response of laser welded sandwich panel under three-point bending test

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**Abstract.** The sandwich structure is known by inner and outer faces which acted compositely with relatively low strength core. Sandwich panel consisted of two thin and stiff skins and separated by a thick and lightweight core. The objective of this study to predict the behaviour of the laser-welded sandwich panel under three-point bending test. Numerical modelling of laser-welded was studied and run under bending loading. The sandwich panels were studied on a different number of the unit cell; 1-core, 2-core and 3-core. The role of a number of web-core to determine overall deformation and local failure response of the sandwich panel was studied. Faceplate and web plate were connected by using diode laser welding. The plates were cut by using sheet metal cutter machine for precise dimension. The sandwich panel modelled by using Abaqus 6.13 version to predict the response of the sandwich panel under bending loading. Cell wall buckling was found as an initial failure in the corrugated core system. The prediction result showed good agreement with experimental measurements.

### 1. Introduction

Started in the 1940s, a sandwich structure applied in the aircraft industry. Then the application developed in missile and spacecraft structures [1]. While at beginning of the 1960s, application of sandwich structure widely prefabricated in the construction field for building element. Sandwich structure system accepted in the construction industry due to high durability, high strength-to-weight ratio, resistance to corrosion and impact and flexibility of design [2]. Davies stated that the sandwich structure was designed in that such way due to the load-bearing unit for expecting service life [3]. The core increased shear capacity and moment of inertia.

In marine application used web-core sandwich beams specifically at the deck of the ship. Concerns of corrosion problem became a priority in this industry. Corrode structure could reduce the strength of the panel and caused the collapse of the structure. Boon et al. and Almusallam studied and observed changes of the stress-strain curve. They found that corrosion could reduce material ductility [4]. Laser welded web-core sandwich panel compared to the traditional stiffened plate [5]. Bending response of laser welded web-core very operative than traditional stiffened plate [6]. Laser welding used to attach between flat web and face plates [7]. Almost all laser welded sandwich structures have high strength. The result gave high performance in shipbuilding, aerospace and civil constructions [8].

In a few studies, Kolster and Zenkert considered buckling and post-buckling of web-core [9]. They studied local buckling and post-buckling of faceplate [10] [11]. While Kozak and Jelovica et al. study on the ultimate strength of sandwich column and global bifurcation buckling strength of sandwich plates [12] [13]. Buckling and post-buckling assessment of stiffened plates developed in two stages. The



assessment approached by Byklum and Amdah [14]. However, studies on the influence of out-of-plane shear deformation not considered. Currently, Romanoff and Nordstrand found that shear deformation gave large effect on sandwich plate response [15] [16].

The aim of this study to compare the response of laser-welded sandwich panel between experimental measurement and numerical modelling.

## 2. Numerical Analysis

The modelling of laser-welded web-core sandwich structure simulated by using Abaqus 6.13 version. The numerical modelling used to predict the bending response of the sandwich panel under three points bending.

### 2.1. Modelling of the Galvanised Iron by using Isotropic

The galvanised iron was modelled by using an isotropic elastoplasticity to predict elastic and plastic behaviour as either a rate-dependent or rate dependent model and it has a simple form.

### 2.2. Elasticity

A model of isotropic linear elasticity was generated for the elastic respond for a material in a numerical analysis. The material that performed the linear elastic behaviour, the total stress defined through this equation [17]:

$$\sigma = D^{el} \varepsilon^{el} \quad 2.1$$

Where  $\sigma$  the total stress,  $D^{el}$  is the fourth order of an elasticity tensor and  $\varepsilon^{el}$  is the total elastic strain. From the Equation (2.1) the stress-strain relationship of isotropic linear elasticity strain.

$$\begin{bmatrix} \sigma_{11} \\ \sigma_{22} \\ \sigma_{33} \\ \sigma_{12} \\ \sigma_{13} \\ \sigma_{23} \end{bmatrix} = \frac{E}{(1+\nu)(1-2\nu)} \begin{bmatrix} 1-\nu & \nu & \nu & 0 & 0 & 0 \\ \nu & 1-\nu & \nu & 0 & 0 & 0 \\ \nu & \nu & 1-\nu & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{(1-2\nu)}{2} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{(1-2\nu)}{2} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{(1-2\nu)}{2} \end{bmatrix} \begin{bmatrix} \varepsilon_{11} \\ \varepsilon_{22} \\ \varepsilon_{33} \\ \varepsilon_{12} \\ \varepsilon_{13} \\ \varepsilon_{23} \end{bmatrix} \quad 2.2$$

The symbol of  $E$  is Young's modulus and  $\nu$  is a Poisson's ration. These are defined in the equation above. The inverse relationship is defined as an equation below:

$$\begin{bmatrix} \varepsilon_{11} \\ \varepsilon_{22} \\ \varepsilon_{33} \\ \gamma_{12} \\ \gamma_{13} \\ \gamma_{23} \end{bmatrix} = \begin{bmatrix} \frac{1}{E} & \frac{-\nu}{E} & \frac{-\nu}{E} & 0 & 0 & 0 \\ \frac{-\nu}{E} & \frac{1}{E} & \frac{-\nu}{E} & 0 & 0 & 0 \\ \frac{-\nu}{E} & \frac{-\nu}{E} & \frac{1}{E} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{G} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{G} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{G} \end{bmatrix} \begin{bmatrix} \sigma_{11} \\ \sigma_{22} \\ \sigma_{33} \\ \sigma_{12} \\ \sigma_{13} \\ \sigma_{23} \end{bmatrix} \quad 2.3$$

$$G = \frac{E}{2(1+\nu)} \quad 2.4$$

$G$  is a shear modulus. The elastic material in the properties of galvanised iron was used in the numerical modelling. The properties were taken from experimental results. The value of Young's modulus,  $E = 216$  GPa and the Poisson's ratio is  $\nu = 0.3$  [18].

### 2.3. Yielding

Isotropic yielding is applied to a von Mises yield surface. The surface is assumed that yielding of a metal is independent where experimental works confirmed the observation. The metal was applied under a positive pressure stress. When the metal applied in the situation of high-pressure stress, inaccurate might be happened because voids could nucleate and grow in the metal [17].

#### 2.3.1. Plasticity

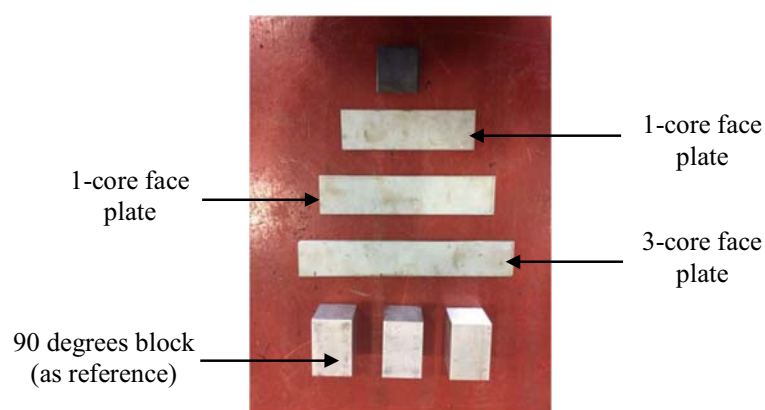
Beyond the yield point is a permanent deformation or called as the plastic behaviour of the aluminium. The plastic behaviour was defined in an isotropic hardening. To describe the isotropic hardening, the yield stress,  $\sigma^0$  which given in a plastic strain tabular function. The interpolation of the yield stress at any plastic strain rate can be done from the table of data.

## 3. Experimental Work

Web-core sandwich panel fabricated by using galvanised iron. A shear cut machine was used to cut the material. The sandwich panel consisted of two plates; web and faceplate. The dimension of the web-core decided as 50 mm x 50 mm x 2 mm and thickness of face plate was 1 mm. Faceplate, web plate and reference block showed in Figure 1. The sandwich panel tested with a different area of the specimen; 1-core, 2-core and 3-core. The reference block used to join and align the plates in. The dimension of all specimens showed as below in Table 1:

**Table 1.** Table of the specimen area

| Specimen | Dimension |
|----------|-----------|
| 1-core   | 50 x 178  |
| 2-core   | 50 x 230  |
| 3-core   | 50 x 303  |



**Figure 1.** Face and web plates

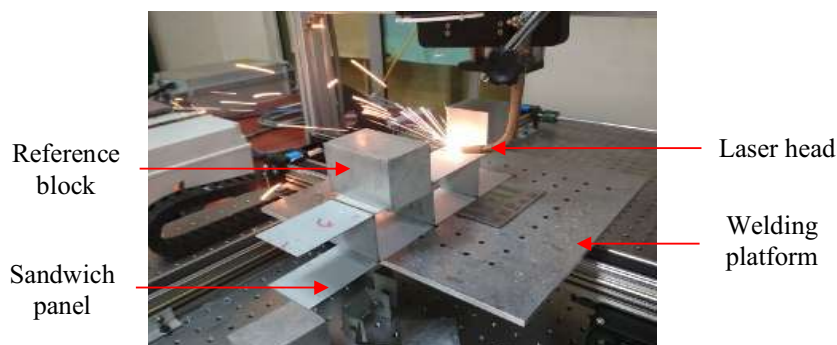
### 3.1 Laser welding

The web and faceplate joint by using diode laser welding as shown in Figure 2. Before welding, the material needs to be cleaned because some sheet metals have a coating which to prevent from rusting.

Sandpaper sheets used to remove the coated layer and cleaned the surfaces by using acetone. A jig was used during set up the sandwich panel for laser welding. Besides that, it also used to fix the position of the sandwich panel during laser welding. Power control of laser welding was set up with specific parameters. The parameters showed in Table 2 below:

**Table 2.** Parameters of laser welding

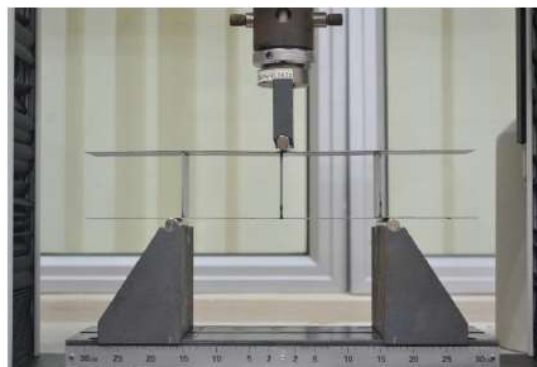
|                             |       |
|-----------------------------|-------|
| Laser power                 | 80 kW |
| Laser pulse width           | 5 ms  |
| Laser pulse repetition rate | 20 Hz |



**Figure 2.** Laser welding process on sandwich plate

### 3.2 Bending test

The specimen tested by using Universal Testing Machine Instron 3369. While the load cell of the machine is 50 kN. Therefore, load application of 50 kN was decided as a constant variable in this experiment. The software of BlueHill Light would use during conducting the experiments. The method of the experiment could be set up by using this software.

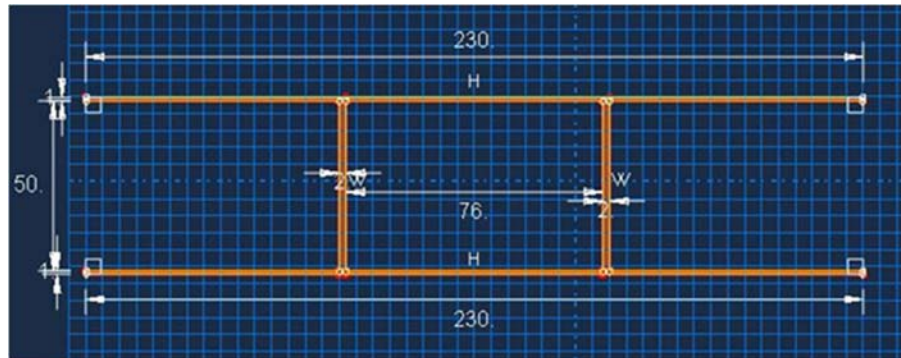


**Figure 3.** 2-core sandwich structure set up by using Instron 3369 testing machine

## 4. Result and Discussion

Finite element analysis of laser welded sandwich panel performed by using Abaqus. The FEA result compared to the experimental result. The purpose of this study was to study the behaviour of laser welded sandwich panel under three points bending by a different number of web core. Table 3 showed a comparison between numerical analysis prediction and experimental result. Figure 4 showed a sketch

of web-core modelled as 3D Deformable. Web-core extruded by using solid extrusion and depth of extrusion was 50 mm.



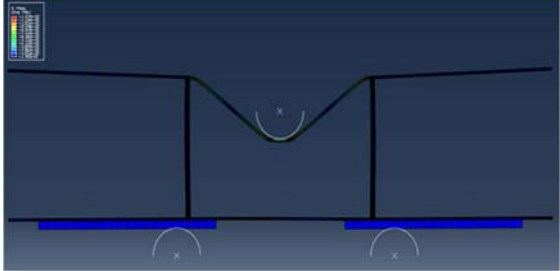

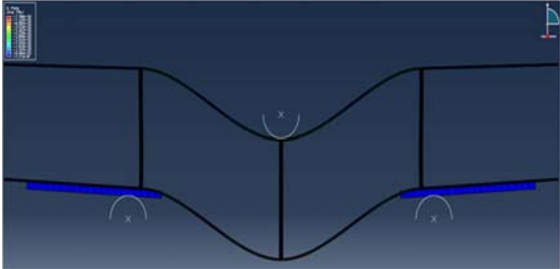

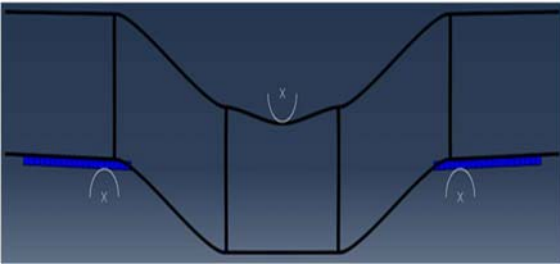

**Figure 4.** Detail dimension of 1-core in FEA

The bending response of sandwich panel in experimental nearly similar to FEA result. Under three points bending test, the whole panel would deform slightly and caused deflection of face plate when the displacement of load increased. The yield strength of the faceplate tends to fail after reaching an elasticity limit. The middle core would support load acted and resulted in higher shear force. In meanwhile, the middle core experienced low stress. Besides that, it also caused the strength of T-joint became decreased. The maximum welding deformations at the edge of face plate were obtained from the displacement of bending loading. Deformation at T-joint got higher when a load keep acting on it [19].

The bending response of a different number of web-core based on the constant speed of laser welding and thickness of plates. According to Table 3, the maximum load of 1-core in experimental testing and FEA was lower than 2 and 3-core sandwich structure. The experimental and FEA value of maximum load for 1-core was 174.31 N and 234.31 N, respectively. From the observation in Table 3, increasing number of web-core could withstand with higher load. While, percentage difference of maximum load for 1-core between experimental measurement and FEA was 29.37 %. However, the result was beyond an expectation. The maximum load value of FEA should be higher than experimental value because FEA model assumed as a perfect model.

Obviously, the response of numerous web cores would accurately reflect one unit cell system [20]. Nevertheless, difficulties concomitant with the manufacturer of single unit web-core samples as well as problems with alignment test would cause unwanted variances into the test data. Tests were done on samples from one to two web-core. A varying number of web-core affected on bending strength of galvanised iron sandwich panel as showed in Table 3. A comparison of displacement between numerical analysis prediction and the experimental measurements at each critical point. The comparison stated that the influence of a different number of web-core was accurately predicted. All sandwich panels subjected to a similar level of crosshead displacement. Failure modes of all three samples were similar such as web-core wall buckling being in confirmation. Buckling of a sandwich panel happened after reaching higher load and one of the struts partially bent. The stiffness of the sandwich panel became decreased. Sample deformation would steadily be decreased when buckling formation related to the parameter of the sandwich panel. Stability of the sandwich panel could reduce due to buckling of plastic. In meanwhile, through an observation in three-point bending test, variant number of unit cells, buckling of elastic was the main initial failure mode for galvanised iron.

**Table 3.** Table of result comparison between FEA and experimental

| Core | FEA   | Experimental   |
|------|---|--|
| 1    |  <p>Maximum load = 174.31 N</p>  |  <p>Maximum load = 234.31 N</p>  |
| 2    |  <p>Maximum load = 168.84 N</p> |  <p>Maximum load = 265.20 N</p> |
| 3    |  <p>Maximum load = 210 N</p>   |  <p>Maximum load = 400 N</p>   |

## 5. Conclusion

Web-core sandwich panel was fabricated by using galvanised iron and used laser welding to join between webs and face plate. The experimental procedures were introduced to produce a lightweight sandwich structure. The response of the sandwich panel was predicted by numerical analysis under three point bending loading. From the observation, failure of buckling initiated by instabilities of the web-core wall as begin to buckle. Beyond of this respond, the galvanised iron deformed plastically and resulted in formation of localised plastic. Prediction result showed good agreement with the experimental result, which providing appropriated value for initial imperfection by FEA. Deformation

of sandwich structure under three-point bending load, which used laser welding technology is an improvement in lightweight structure to produce high strength-to-weight ratio for marine application.

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### References

- [1] Vinson, J., *The behavior of sandwich structures of isotropic and composite materials*. 2018: Routledge.
- [2] Ferdous, W., et al., *Flexural and shear behaviour of layered sandwich beams*. Construction and Building Materials, 2018. **173**: p. 429-442.
- [3] Davies, J.M., *Lightweight sandwich construction*. 2008: John Wiley & Sons.
- [4] Jelovica, J., et al., *Ultimate strength of corroded web-core sandwich beams*. Marine Structures, 2013. **31**: p. 1-14.
- [5] Romanoff, J. and A. Klanac, *Design optimization of steel sandwich hoistable car decks applying homogenized plate theory*. Journal of Ship Production, 2008. **24**(2): p. 108-115.
- [6] Klanac, A. and P. Kujala, *Optimal design of steel sandwich panel applications in ships*. PRADS, Lubeck-Travemuende, 2004: p. 907-914.
- [7] Romanoff, J. and P. Varsta, *Bending response of web-core sandwich beams*. Composite Structures, 2006. **73**(4): p. 478-487.
- [8] Sun, Y., et al., *Analysis and Experiment on Bending Performance of Laser-Welded Web-Core Sandwich Plates*. Materials Today: Proceedings, 2015. **2**: p. S279-S288.
- [9] Kolsters, H. and D. Zenkert, *Buckling of laser-welded sandwich panels. Part 1: Elastic buckling parallel to the webs*. Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment, 2006. **220**(2): p. 67-79.
- [10] Kolsters, H. and D. Zenkert, *Buckling of laser-welded sandwich panels. Part 2: elastic buckling normal to the webs*. Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment, 2006. **220**(2): p. 81-94.
- [11] Kolsters, H., *Structural design of laser-welded sandwich panels for marine applications*. 2004, Farkost och flyg.
- [12] Kozak, J., *Problems of strength modelling of steel sandwich panels under in-plane load*. Polish Maritime Research, 2006: p. 9-12.
- [13] Jelovica, J., et al., *Influence of weld stiffness on buckling strength of laser-welded web-core sandwich plates*. Journal of Constructional Steel Research, 2012. **77**: p. 12-18.
- [14] Hahn, E.K., et al., *Compressive strength of edge-loaded corrugated board panels*. Experimental Mechanics, 1992. **32**(3): p. 259-265.
- [15] Romanoff, J., et al., *The stiffness of laser stake welded T-joints in web-core sandwich structures*. Thin-Walled Structures, 2007. **45**(4): p. 453-462.
- [16] Nordstrand, T., *On buckling loads for edge-loaded orthotropic plates including transverse shear*. Composite Structures, 2004. **65**(1): p. 1-6.
- [17] Nowak, T., *Elastic-plastic behavior and failure analysis of selected Fiber Metal Laminates*. Composite Structures, 2018. **183**: p. 450-456.
- [18] Duarte, A.P.C., A. Díaz Sáez, and N. Silvestre, *Comparative study between XFEM and Hashin damage criterion applied to failure of composites*. Thin-Walled Structures, 2017. **115**: p. 277-288.
- [19] Kim, J.W., et al., *A study on an efficient prediction of welding deformation for T-joint laser welding of sandwich panel PART I : Proposal of a heat source model*. International Journal of Naval Architecture and Ocean Engineering, 2013. **5**(3): p. 348-363.
- [20] Rejab, M. and W. Cantwell, *The mechanical behaviour of corrugated-core sandwich panels*. Composites Part B: Engineering, 2013. **47**: p. 267-277.