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Three-point bending response of Laser-Welded Sandwich Structure with varying number of core and span length

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Abstract. Laser welding offered multiple benefits for production of all-metal and hybrid-metal sandwich structure. Deep penetration of laser welding required high energy intensity and low heat input. Normally, steel sandwich structure dominated failure features. The objective of this study to investigate the failure of laser-welded sandwich structure under three-point bending test. Bending deformation of the sandwich structure was studied with numerical modelling. The sandwich panels were studied on different number of core and span length of experimental. The role of core number to determine overall deformation and local failure response of the sandwich panel were studied. Face and web plates were assembled perpendicularly via fibre laser welding. The sandwich panel modelled by using Abaqus to predict response of the sandwich panel under bending loading. The aim of this study to compare response of laser-welded sandwich panel from experimental work and numerical modelling. Different span length and core number affected cell wall buckling in corrugated core system. The comparison result showed good agreement with experimental measurements. Percentage error between experimental and FE analysis was 25.60%.

Keywords. Sandwich structure; Laser welding; Three-point bending; FEA.

1. Introduction

A sandwich structure was launched in the 1940s and implemented in the aviation sector. The application then evolved in the structures of missiles and spacecraft [1]. While the implementation of sandwich framework was largely prefabricated for building component in the construction sector at the start of the 1960s. Sandwich structure system accepted in the construction industry because of its high durability, high resistance to weight ratio, corrosion strength and design flexibility [2]. Davies indicated that the structure of the sandwich has built in this manner because of the load-bearing unit for life expectancy [3]. The core has improved shear ability and inertia moment [4].

Web-core sandwich structures were used specifically on the ship's deck in marine applications. Corrosion concerns have become a concern in this sector. Corrode structure may have reduced panel strength and caused structure collapse. Boon et al. and Almusallam studied changes in the stress-strain curve and noted them. They discovered that corrosion might decrease the ductility of the material [5]. Compared to traditional reinforced plate, laser welded web-core sandwich panel [6]. Laser welded web-core bending reaction very operative than traditional rigid plate [7]. Laser welding used to fit flat

web and face sheets [7]. Nearly all sandwich structures welded by laser have high strength. The outcome was good performance in shipbuilding, aerospace and civil constructions [8].

Kolster and Zenkert regarded web-core buckling and post-buckling in a few studies [9]. They were studying local buckling and faceplate post-buckling [10, 11]. While Kozak and Jelovica et al. were studying the ultimate strength of the sandwich column and the global bifurcation on buckling strength of sandwich plate [12][[13]. Buckling and post-buckling evaluation evolved in two phases of stiffened plates. Byklum and Amdah approached the evaluation [14].

However, out-of-plane shear deformation studies were not regarded. Romanoff and Nordstrand discovered that shear deformation had a major impact on the reaction of sandwich plate [15, 16]. The aim of this research is to investigate bending performance on variant number of core and span length. The experimental findings of the three-point bending experiment will be compared with the outcomes of the finite element assessment from this research.

2. Mathematical modelling

Laser-welded web-core sandwich structure modelling simulated using the version of Abaqus 6.13. The numerical modelling used to forecast the sandwich panel's bending reaction under three bending points. Galvanized iron was simulated using isotropic elastoplasticity to forecast elastic and plastic behaviour as either a model based on frequency or frequency, and it has a straightforward form. In a numerical analysis, an isotropic linear elasticity model was generated for the elastic response to a material. The material performing the linear elastic behaviour, the complete stress defined by this equation [17]:

$$\sigma = D^{el} \varepsilon^{el} \tag{1}$$

σ is noted as the total stress. D^{el} is included in the fourth order of an elasticity tensor and ε^{el} is the total elastic strain. E and υ are Young's modulus and Poisson's ratio, respectively. These are defined in the equation below. In the table 1 showed mechanical properties of galvanised iron. The inverse relationship is described as the following equation [4, 17, 18]:

$$
\begin{bmatrix} \varepsilon_{11} \\ \varepsilon_{22} \\ \varepsilon_{33} \\ \gamma_{12} \\ \gamma_{13} \\ \gamma_{23} \end{bmatrix} =
\begin{bmatrix}
\frac{1}{E} & \frac{-\upsilon}{E} & \frac{-\upsilon}{E} & 0 & 0 & 0 \\
\frac{-\upsilon}{E} & \frac{1}{E} & \frac{-\upsilon}{E} & 0 & 0 & 0 \\
\frac{-\upsilon}{E} & \frac{-\upsilon}{E} & \frac{1}{E} & 0 & 0 & 0 \\
0 & 0 & 0 & \frac{1}{G} & 0 & 0 \\
0 & 0 & 0 & 0 & \frac{1}{G} & 0 \\
0 & 0 & 0 & 0 & 0 & \frac{1}{G}
\end{bmatrix}
\begin{bmatrix} \sigma_{11} \\ \sigma_{22} \\ \sigma_{33} \\ \sigma_{12} \\ \sigma_{13} \\ \sigma_{23} \end{bmatrix} \tag{2}
$$

Table 1. Table of mechanical properties for galvanized iron [4, 17, 18].

Properties	Value
Density , ρ	7.4205 kg/m^3
Young's modulus, E	216 GPa
Poisson's ratio, υ	0.3

2.1. Plasticity

A permanent deformation is beyond the yield point or called as the plastic behaviour. In an isotropic hardening, the plastic behaviour was described onto aluminium. The isotropic hardening was defined in plastic behaviour. It is possible to interpolate the yield stress at any plastic strain rate from the data table [4, 17].

2.2. Yielding

Isotropic yielding is applied to a yield surface of von Mises. The surface is presumed to be independent of producing a metal where the observation was verified by experimental works. Under positive pressure stress, the metal was applied. When the metal was applied in a high-pressure stress scenario, inaccuracy could occur because voids in the metal could nucleate and develop [4, 17]. In figures 1 and 2 showed sketch of 2-core and meshing of sandwich structure, respectively. The model was designed as 3D Deformable. The web plate was extruded 50 mm with solid extrusion. The width of web plate 50 mm.
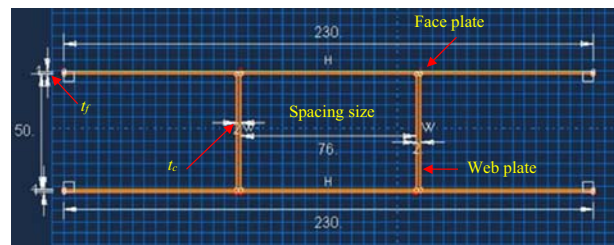

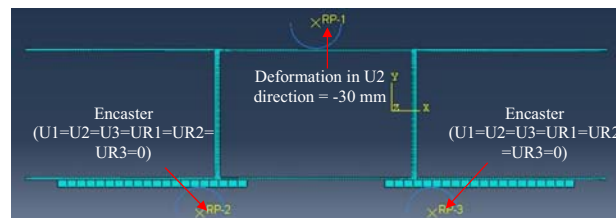**Figure 1.** Detail dimension of 2-core in FEA.

Figure 2. 2-core sandwich structure with meshing.

3. Experimental work

Web-core sandwich panel made from galvanized iron. For cutting the material, a shear cutting machine was used. There were two plates on the sandwich structure; web and face plates. Web-core dimensions chosen as 50 mm × 50 mm × 2 mm. Face plate thickness was fixed to be 1 mm. Face plate, reference block and internet plate shown in figure 3. The sandwich structure was tested with different number of core 1-core, 2-core, and 3-core. The reference block in which the plates were joined and aligned. The size of all samples shown in table 2.

Table 2. Table of specimen area.

Specimen	Dimension (w x l) (mm^2)	Spacing size, s	Height, H ($t_f + h$)	$t_f = t_c$
2-core	50 x 230	75	50	1
3-core	50 x 308	75	50	1
4-core	50 x 386	75	50	1

Figure 3. Face and web plates.

3.1. Laser welding

Web and face sheet were joint using fibre laser welding as illustrated in figure 4. Before welding, the material surfaces were cleaned due to some sheet metals having a coating and dust. The use of acetone was used to remove the coated layer with sandpaper and to clean the surfaces. A jig was used during the set-up of laser welding. Furthermore, during laser welding, the location of the sandwich framework would be fixed. The blocks were used as a reference to joint web and face plates in 90 degrees. Specific parameters were used to set laser welding power control. The following parameters are shown in table 2:

Table 3. Parameters of laser welding [4].

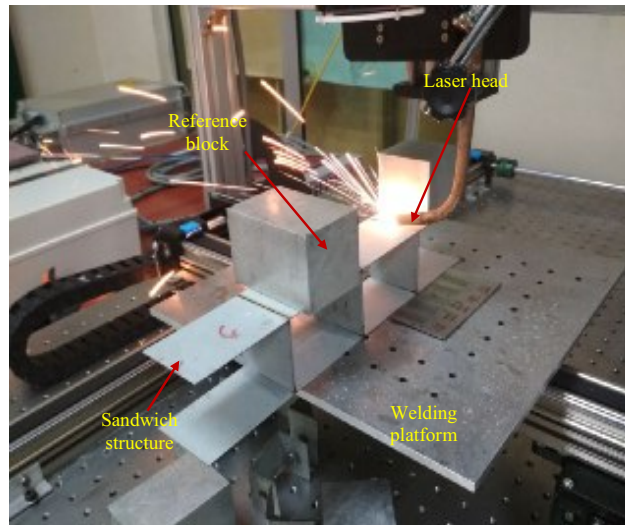| Parameter	Symbol	Value
Laser power	W	80
Laser pulse width	ms	5
Laser pulse repetition rate	Hz	20

Figure 4. Laser welding process on sandwich plate.

3.2. Bending test

The sample was evaluated using the Universal Testing Machine from Instron 3369. On the machine were installed a few strain gauges. Outputs such as force, strain displacement, and velocity were worked on by the strain gauges. While the machine's load cell is 50 kN. The software of BlueHill Light was used to calibrate the test. Using this software, the experiment procedure could be established. The bending test for the4-core sandwich framework was shown in the illustration of figure 5.
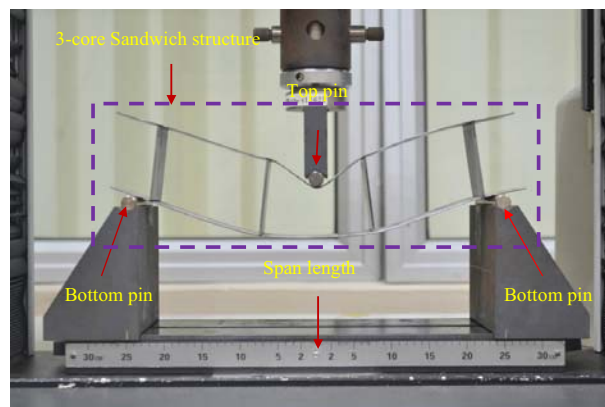

Figure 5. 4-core sandwich structure set up by using Instron 3369 testing machine.

4. Results and discussions

Deformation of laser-welded sandwich structure was analysed through results of three-point bending test and finite element analysis. The experimental results were compared with the finite element analysis results. Performance of laser-welded sandwich structures were compared with varying number of core and span length.

4.1. Effect of core number
Bending response of the sandwich structure was almost comparable to the FEA consequence. The entire structure would deform slightly under a three-point bending test and triggered on the face plate when load and displacement increased. The faceplate yield strength tends to fail after an elasticity threshold has been reached. The middle core would have been acting to sustain the load, resulting in increased shear force. Meanwhile, low stress was encountered by the middle centre. In addition, it also induced a decrease in T-joint strength.

The result of the evaluation of experimental and finite elements was contrasted in load-displacement trace between 2-core,3-core and 4-core as shown in figures 6 and 7 respectively. Obviously, one unit cell system would correctly represent the reaction of various web cores [18]. T-joint deformation increased when a load continues to act on it [19]. The laser-welded sandwich constructions at the T-joint have defects. The defects were taken into consideration. The T-joint area as showed in figure 8 was observed under optical microscope. In the illustration, there was a root gap. In the root gap filled with filler material. Brittle would easily occurred at the area. The brittle could cause bending resistance of the sandwich structure turn to decrease. Penetration depth of laser welding was 0.78 mm. Besides root gap, the strength of the sandwich structure could affect from weld width of laser welding [15, 20, 21]. Input of laser welding played significant role to determine weld quality of joint. The quality could be determined from properties of weld, geometry of weld and distortion. Hence. The mechanical properties needed be controlled to achieve good joint of weld [4, 22, 23].

Testing was carried out on 2-core, 3-core and 4-core specimens. The bending resistance of the galvanized iron sandwich structure was affected by varying number of web-core as shown in figure 9. The sample comparison was based on the maximum load of the samples. Failure methods of all three samples were comparable to confirmation of web-core local deformation. After achieving maximum load, deformation was occurred on the sandwich structure and one of the web plate partially bent.

The sandwich panel's stiffness was reduced. When deformation linked to the sandwich structure geometrical size. Sample deformation would be continuously reduced due to number of core. The sandwich panel's stability could be reduced owing to plastic deformation. Meanwhile, deformation of elastic was the primary original failure mode for galvanized iron through an observation in three-point bending experiment, variant number of core [4].

4.2. Effect of span length
Bending strength of the laser-welded sandwich structure was compared with different span lengths. Mechanical property such as. The span length became bigger when number of core increased. With increasing the supporting span length, depth of deflection would increase linearly [24]. Varshneya and Scheeweiβ were discovered that bending strength reduced due to supporting span length increased [25, 26]. Lee found that Young's modulus increased with decreasing the span length.

Other than that, bending strength was depending of its measuring condition [24]. From the load-displacement trace as showed in figure 6, with decreasing the span length bending strength was getting increased from 205.516, 264. 902 and 418.937 N. In figure 9 also showed the experimental set up for 2-core, 3-core and 4-core with different span length. The span length in figure 9(a), (b) and (c) were 9.5, 17 and 25 mm, respectively.
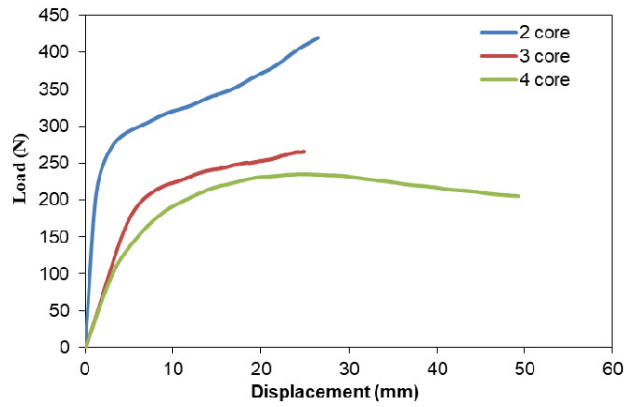
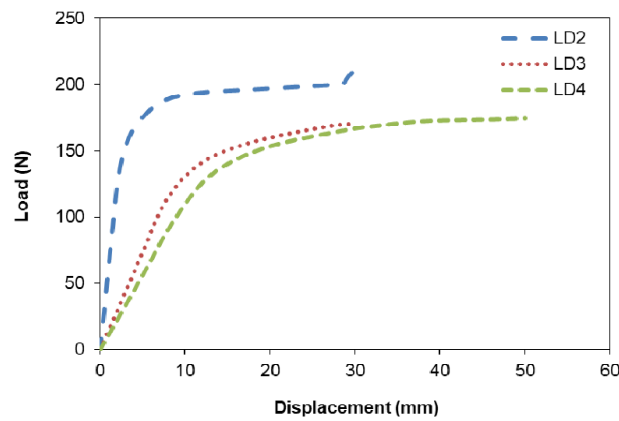**Figure 6**. Comparison result of variant core numbers from experimental.

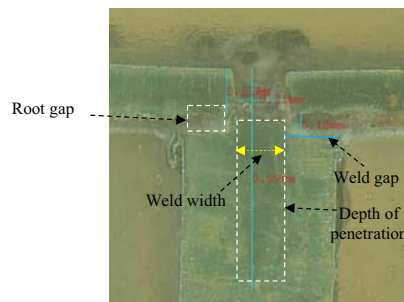

Figure 7. Comparison result of variant core numbers from FEA.
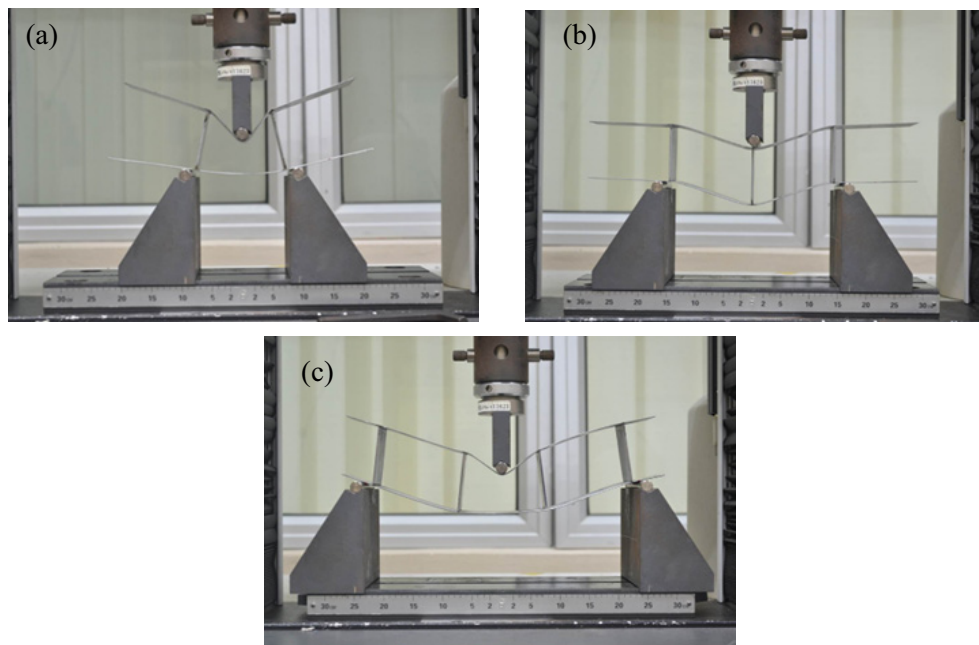

Figure 8. Root gap of T-joint.

Figure 9. Deformation of sandwich structure with different core number and span length.

5. Conclusion

Sandwich structure was used material of galvanised iron to fabricate web-core sandwich structure. The structure was used technology of fibre laser welding to join web and face plates perpendicularly. In order to create a lightweight sandwich structure, the experimental processes were implemented. The sandwich structure response was simulated under three-point bending test. The experimental data was compared with numerical analysis results. Based on figure 5, maximum load of each sample was recorded in load-displacement trace. The highest value of bending strength among the samples was 418.937 N. The sample was able to withstand the machine's load of 50 kN with a displacement of 30 mm. From the observation, deformation failure started by instabilities of web-core wall. In addition to this response, the galvanized iron plastically deformed and localized plastic was formed. A whole performance of the sandwich structure was also affected by the T-joint. The result of the comparison showed good agreement with the experimental measurements. 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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