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Experimental and Finite Element Analysis of Laser Stitch Welded Structure

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ABSTRACT

Nowadays, the application of laser stitch welding in automotive manufacture has dramatically increased due to its capability in producing lightweight joints. The dynamic characteristics of laser stitch welded joints are important to be analysed in order to understand the effect of the joint towards the noise, vibration and harshness (NVH) of the assembled structure. However, the accuracy of dynamic characteristics of the finite element model is differ from the experimental data due to the invalid assumptions of the input value of the model properties. Understandably, physical phenomenon of the laser stitch welded joint is complex and consist of many uncertainties in order to model in details. In this paper, a few joint connectors are investigated to represent laser stitch welded joints by using finite element modelling method. In this paper, a different type of element connectors such as rigid body element (RBE), shell element and solid element format are explored to represent laser stitch weld joints of a thin plate welded structure. The predicted results of different types of element connectors are then compared in term of natural frequencies and mode shapes with the experimental counterparts. The comparisons of results reveal that shell element has better capability to represent laser stitch welded joint in comparison with other element connectors.

Keywords: *Laser stitch weld, Dynamic characteristic, Experimental modal analysis, Finite element analysis.*

Introduction

Commonly in automotive industries, a mechanical component are assembled together to form a large and complex structural member such as automotive structure. The components are then assembled together by thousands of joints such as rivets, bolts or welds in order to form a car's body-in-white (BiW). Therefore, the stability and dynamics characteristics of the structures are highly depends on the joints [1-3].

Laser stitch welds is one of the advances joining technology that are increasingly used in the automotive manufacturing industry to fulfil the need in producing a lightweight car structure. Furthermore, the lightweight structure

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is able to provide a significant impact in improving fuel efficiency. Despite producing a highly accurate of joints, the local effects of laser stitch welds are realised to be complex and also influenced by many uncertain parameters when it is required to be investigated numerically [4]. Thus, a computerised analysis package such as finite element method is found to be more beneficial to predict the dynamic characteristics of the structure based on assumption of geometrical model and material properties. There are a few types of element connectors that are widely used to represent welded joints such as RBE2, CWELD and ACM2 format [5]. For instance, Xia et al. have used CWELD to model spot welds to represent the jointed structure [6]. Furthermore, Heiserer et al. has used ACM2 to represent spot welded joints [7]. There are a few studies that related to the application of shell, solid, CWELD, RBE2 and ACM2 element by using finite element method [8-12]. Furthermore, Rani et al. reported the advantages of the use of CWELD element connector to represent laser welded joints in comparison with ACM2 element connector [13]. However, there are very few papers that discussed about the finite element models of the laser stitches welded joints. Therefore, a continuous study to investigate numerically the potential element connectors to represents the laser welded joints needs to be conducted. It is particularly because of the dependency of dynamic characteristics of assembled structures toward element connectors [12-17].

Therefore, this paper is concerned with the development of the finite element model of a laser stitch welded structure. The predicted result of dynamic characteristics of models structure are compared with the measured counterparts to find out which one is the most capable element connector to represent as laser stitch welded joints.

Finite Element Modelling

Analytical method such as finite element analysis is known as method that involves discretise the physical domain and the geometry of the structure into small elements. It is a technique used to analyse the modelled structure. Engineers apply this technique to produce a reliable design according to design specification before proceeding to manufacturing process.

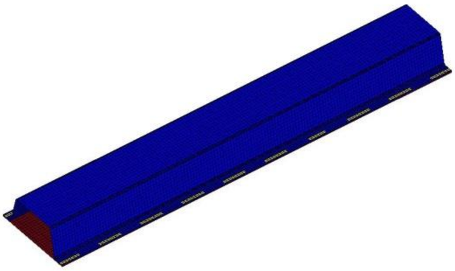


Figure 1: The finite element model of laser stitch welded structure

The laser stitch welded joint structure as shown in Figure 1 was constructed using finite element analysis software package. The normal mode analysis was used to obtain the natural frequencies and mode shapes by solving the Eq. (1). The structures was discretised into a shell element type which represents 1.5mm for their thickness. In this work, the modelling of the laser stitch weld joint was constructed using three different element connectors.

$$(\mathbf{K} - \omega^2 \mathbf{M})\phi = 0 \tag{1}$$

There were three different types element connectors used to represent the laser stitch welds structure namely, rigid link element (RBE2), shell and solid element. A total of twenty element connectors were constructed in every three different models. These produce three different finite element models of laser welded structure with different types of element connectors.

The dynamic characteristics of different types of element connecters were predicted using normal mode analysis (natural frequencies and modes shapes). Meanwhile, the material properties of the model were shown in Table 1. Modes of interest for this research were the first ten elastic modes starting from 1 to 1000 Hz. The minimum frequency of interest was set at 1 Hz to avoid the solver from calculating the first six rigid body modes where it has the frequency of below 1 Hz [10]. Load and constrain were not be assigned in order to simulate the free-free boundary conditions.

Table 1: Details of the finite element model of the laser stitch weld structure

Type of Elements	No of Elements	Properties	Value
Shell	12972	Young's Modulus	210 GPa
		Poisson's Ratio	0.33
		Density	7460kg/m^3

Table 2: Details of the finite element model of laser stitch weld joints

Type of Elements	No of Element	No of Nodes
Shell	118	276
Solid	118	552

Table 3: Details of the properties for laser stitch weld joints

Properties	Value
Young's Modulus	210 GPa
Poisson's Ratio	0.33
Density	7460kg/m^3

Experimental Modal Analysis

Experimental modal analysis is a technique to define the dynamic characteristic of the structure from a vibration testing, in terms of natural frequencies, mode shapes and damping ratios [18, 19]. The result from the experimental data will be compared with finite element model to identify the correlation between experimental data and the finite element predicted results. If the results from the test structures are agreed with predicted model, and then finite element model can be used in further analysis with higher degrees of confidence [20].

In this research, two component structures connected with twenty laser stitch welded as shown in Figure 2 were used as test structure. The components were made of cold rolled mild steel sheets with 1.5mm thickness, 560 mm length and 110 mm wide. Every stitch weld has 10mm length with 1mm width. The distance between each stitch weld was 30mm apart. Prior to perform the modal testing, experimental factor such as frequency bandwidth, suspension orientation, excitation method and number of accelerometers need to be considered from finite element analysis.

In order to replicate the free-free boundary conditions, four sets of nylon strings and springs were used to hang the structure from the clamps. Nylon string and spring were used to suspend the structure because it has very minimal effect (lightly damped) on test structure and can be neglected. The frequency bandwidth of interest of the test structure was 1Hz to 1000Hz.

In this test, the dynamic characteristics of test structure were obtained using impact hammer and roving accelerometers. An impact hammer was used to excite the structure with one fixed reference accelerometer. Meanwhile, the remaining three accelerometers were roved around to completely measure the response. It is important to arrange accelerometers systematically in order to avoid any mass loading issues to the test structure during experimental process. Finally, LMS SCADAS system was used to interpret the load and signal produced by test structure.

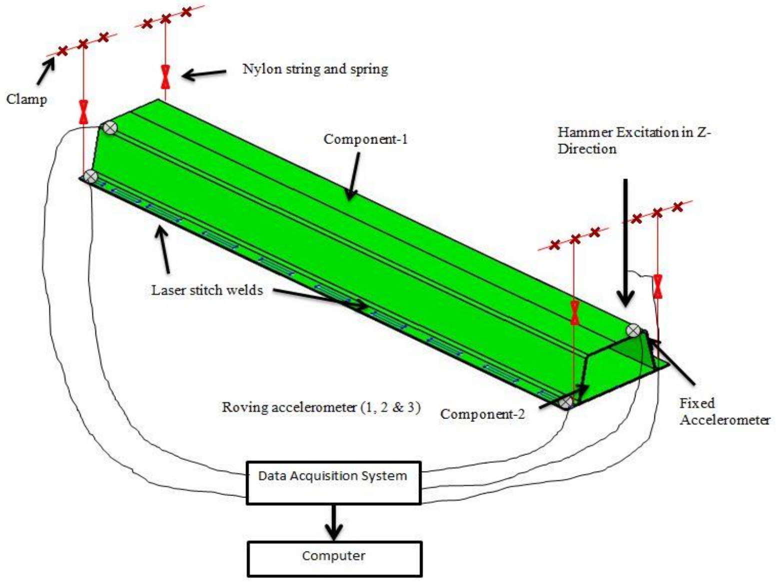


Figure 2: Schematic diagram of the experiment setup of the laser stitch welded structure

Results and Discussion

In this study, dynamic characteristics of welded structures which are natural frequencies and mode shapes were obtained and compared experimentally and numerically to confirm the accuracy of the predicted model. Prior to the mode analysis, the structures were firstly discretised and modelled using shell element. In order to identify the modal parameters, three different types of element connectors such as RBE2, shell and solid were applied to represent the laser stitch welds joints. Normal mode analysis was used to obtain the behaviour of structure in terms of natural frequencies and mode shapes. LMS SCADAS was used in experiment modal analysis. Results obtained using the above mentioned methods were showed in Tables 4, 5 and 6.

Table 4 shows the results of the natural frequencies between experimental and numerical results of laser stitch welded structure. The results only take account on first until third mode shapes of three different element connectors. The solid based model is recorded as the largest inaccuracy with total relative error of 10.22 percent (column VI) and the average relative error of 3.41 percent. The third mode with 3.94 percent is the greatest error contribution. These result shows that there are limitations in the solid element connector in representing laser stitch welds. The highest relative errors are indicated that solid element connector is too stiff and not enough capability to represent as laser stitch welded joints. Theoretically, the limitation of solid element connector is due to this type of elements will increase the number of nodes used in the development of a finite element model and it does not possess the bending behaviour [21].

From Table 4, the results show that RBE2 based model total relative error are 5.32 percent (column IV) and with average relative error of 1.77 percent. It can be observed that RBE2 based model have a better accuracy in comparison with the solid based model. However, RBE2 element connector is a type of connector that distributes high stiffness of connections between the structures component. Previous study suggest that RBE2 element connectors is a perfect selection to enforce the exact rigid constrain between structures component [22]. Thus, RBE2 element connector can be said as far below the capability required to represent as laser stitch welded joint with an acceptable level of accuracy.

Finally, the third element connector used to represent laser stitch welds joint is shell elements. This type element connector is producing total relative error of 4.53 percent (column VIII) and with average relative error of 1.51 percent. The highest relative error was contributed by first mode with 2.92 percent. From result above, it can be seen that, shell element connector is provided high accuracy to be used in modelling the laser stitch welded structure in comparison with another two different element connectors which are solid and RBE2.

In column VIII, shell element based model was noted as the most successful finite element model in terms of the individual and total percentage error of three modes when compared with experimental counterparts. On top of that, the observation of the result can strongly agree that the predicted natural frequencies of laser welded structures can be varying by manipulating element connector. Based on this results, the shell element based model has a better accuracy in predicting dynamics characteristics of laser stitch welded structure compared with solid and RBE2.

The results in Table 5 and Table 6 shows the comparisons of the measured data and predicted result based on the natural frequencies and mode shapes that were obtained from the laser stitch welded structure. As can be seen in Table 5, the natural frequencies were successfully predicted by the three element connectors but with different levels of accuracy. However, from the results, only first three modes have shown good agreement with measured counterpart. The predicted results of fourth and fifth mode as shown as in Table 6 were not in good correlationship to be considered as mode shapes of laser stitch weld structure. These results suggest that there are some invalid assumptions made in development of finite element model of laser welded structure. One of that is the existence of initial stress on laser welded structures. In finite element model, the initial stress on structure was not considered since it is difficult to be estimated. Another significant invalid assumption might occur due to inconsistency of stitch length. The stitch lengths are important in finite element since it becomes the benchmark on how many element connectors need to implement in model.

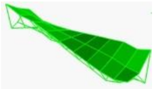
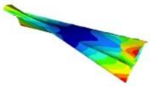
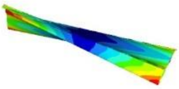
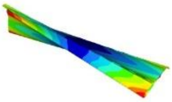
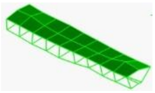
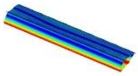
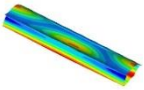
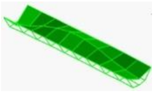
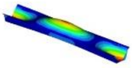
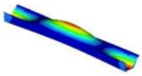
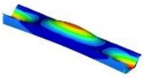
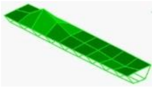
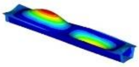
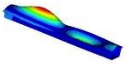
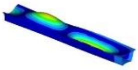
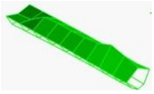
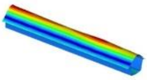
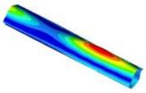
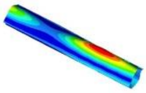
Table 4: The comparison of the total error of the natural frequencies between measured data and predicted result of laser stitch welded structure

I Mode	II Measured (Hz)	III RBE2 (Hz)	IV Error (%) II-III	V Shell (Hz)	VI Error (%) II-V	VII Solid (Hz)	VIII Error (%) II-VII
1	521.84	537.94	3.09	537.08	2.92	541.07	3.69
2	578.98	589.09	1.75	587.72	1.51	594.00	2.59
3	589.32	592.20	0.49	589.91	0.10	612.52	3.94
Total Error (%)			**5.32**		**4.53**		**10.22**

Table 5: The comparison of the natural frequencies between measured data and predicted result of laser stitch welded structure

I Mode	II Measured (Hz)	III RBE2 (Hz)	IV Error (%) II-III	V Shell (Hz)	VI Error (%) II-V	VII Solid (Hz)	VIII Error (%) II-VII
1	521.84	537.94	3.09	537.08	2.92	541.07	3.69
2	578.98	589.09	1.75	587.72	1.51	594.00	2.59
3	589.32	592.20	0.49	589.91	0.10	612.52	3.94
4	678.45	662.11	2.41	657.78	3.05	683.37	0.73
5	690.95	669.29	3.14	665.99	3.61	688.36	0.38

Table 6: The comparison of the mode shapes between measured data and predicted result of laser stitch welded structure

Mode	Measured mode shape	Finite element connector type		
		RBE2	Shell	Solid
1				
2				
3				
4				
5				

Conclusion

This research was conducted to investigate the dynamic characteristics of the laser stitch welded structure by using three different types of element connectors namely, RBE2, shell and solid. In this paper, the modal parameters such as natural frequencies and mode shapes of laser stitch welded structure were investigated and presented. Both results from measured data and predicted results were compared to find out the most reliable element connector to represent as laser stitch weld joint.

The comparison of results reveals that shell based model has shown a better capability to be used to represent as laser stitch weld joints. The accuracy of shell based model as a result of capability shell element in producing a reasonable stiffness to the finite element model of laser stitch welds. However, the accuracy of correlation between the measured data and predicted results can be improved by applying the modal based updating method to the finite element model of welded structure which will be applied to the next stage. Furthermore, continuous study is recommended in modelling the laser stitch welded structure.

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