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Finite element normal mode analysis of resistance welding jointed of dissimilar plate hat structure

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Abstract. Structural joints offer connection between structural element (beam, plate, solid etc.) in order to build a whole assembled structure. The complex behaviour of connecting elements plays a valuable role in characteristics of dynamic such as natural frequencies and mode shapes. In automotive structures, the trustworthiness arrangement of the structure extremely depends on joints. In this paper, top hat structure is modelled and designed with spot welding joint using dissimilar materials which is mild steel 1010 and stainless steel 304, using finite element software. Different types of connector elements such as rigid body element (RBE2), welding joint element (CWELD), and bar element (CBAR) are applied to represent real connection between two dissimilar plates. Normal mode analysis is simulated with different types of joining element in order to determine modal properties. Natural frequencies using RBE2, CBAR and CWELD are compared to equivalent rigid body method. Connection that gives the lowest percentage error among these three will be selected as the most reliable joining for resistance spot weld. From the analysis, it is shown that CWELD is better compared to others in term of weld joining among dissimilar plate materials. It is expected that joint modelling of finite element plays significant role in structural dynamics.

1. Introduction

Lightweight based materials experience high demand in the application of automotive industries due to environment reason and social pressure [1]. Properties of joints for lightweight automotive parts are greatly influenced the stiffness and fatigue behaviour of the structure model [2]. Connections joining are crucial parts of complex structure and play a significant function in the assembled structure's behaviour in the aspect of flexibility and damping. There are numerous kinds of connection used in the engineering structure currently, such as bolts, screw, rivet and clinching which provides good advantages in term of is assembly ability, simple surface preparation, simple expectation of joint failure, ease in the inspection process, easy handling and machining, short assembly and joining times [3]. However, joints can be sensitive to temperature and moisture besides may enhance more weight to the structure [4]. Predicting rigid connections between substructures in modelling by neglecting the joints effect may lead to the different characteristics than actual physical structure. Modal analysis can be defined as an approach of characterizing process for dynamic properties of an elastic structure by identifying its modes of vibration and become a major technique to determine dynamic characteristics of engineering structures and its components [1, 5]. Normally, each mode has a specific natural frequency, mode shapes and damping factor which can be identified from practically any point on the structure either by numerical or experimental methods [6, 7]. In order to design a structure model to be applied in real life, it is essential to execute a materials suitability and structural analysis first so that the result from analysis can predict the effectiveness of material, methods and properties that going to be used practically [8]. In this paper, modal analysis which focusing on numerical study of top hat structure is going to be explores. A major concern in analyzing practical mechanical structures is to reliably identify their dynamic characteristics, i.e., their natural frequencies and vibration mode shapes. These vibration characteristics are needed in order to achieve effective design and control of the vibrations of structural components [9]. The main purpose of this paper is to investigate the most suitable joining method for the analysis of top hat structure which resembles spot welding connection.

2. Plate Hat Modelling

Nowadays, current automotive industry focusing on reducing fuel consumption and cost deduction in the producing vehicle [8]. One of the methods to achieve these goals is by choosing the right joining method between materials. Usually, complete set of automotive body-in-white (BIW) is made up from several combinations of substructures which also contribute to the stiffness and strength of the car body. In this paper, one of the substructures which is top hat is designed to resemble the automotive part and can be seen in Figure 1.

Figure 1. Substructure of automotive parts. [10]

Top hat structures are designed using MSC Nastran Patran with specified dimension as shown in Figure 2. In geometry section for modelling purpose, the easiness of stainless steel to be bend allow the shaping of this material to be at the top while bottom surface is made up of mild steel.

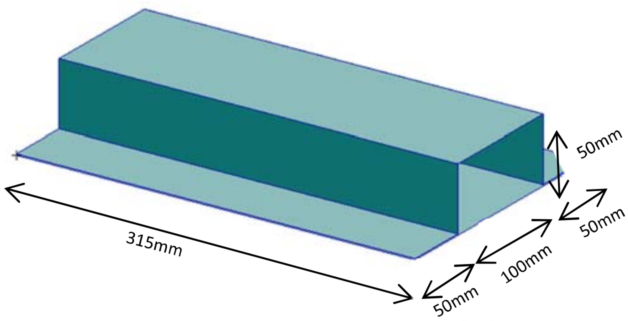

Figure 2. Geometry design of top hat structure.

After design stage is completed, top hat structure is meshed equally and there are 2050 elements involved. Choosing the right meshing size is very crucial because it allow the correct simulation results while deducted the model's complexity as much as possible [11, 12]. Conversely, tiny mesh will also upturn the calculation period needed to finish the simulation [13]. The size of element is picked and confirmed after conducting convergence test where the element size is lessened gradually until the value of natural frequency is converge [12]. Furthermore, based on FEA theory, the smaller the element size which is due to the fine mesh, will increase the accuracy of the result even though the computing time is rather higher than that one with bigger element size [14, 15]. Figure 3 shows top hat structure after meshing process.

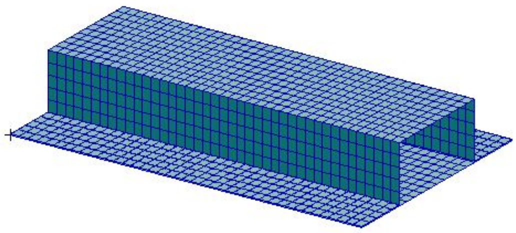

Figure 3. Meshed top hat structure.

Mild steel and stainless-steel properties such as Young's modulus, density and poisson ratio are inserted in finite element calculation. Table 1 shows the properties of those materials.

Table 1. Nominal values of materials

Properties	Mild Steel 304	Stainless steel 1010
Poisson Ratio	0.30	0.27
Young Modulus	210 GPa	200 GPa
Density	7870 kg/m^3	8000 kg/m^3

3. Finite Element Analysis (FEA)

As the behavior of bolted joints plays an imperative function in the dynamic characteristics of structures, the necessity for emerging precise predictive models of the joints is very demanding [16]. The purpose of numerical modelling can be categorized into three different main parts which are analysis, prediction and design [7]. That is the reason why development of finite element has been introduced in order to ease process of analyzing. Finite element analysis can be defined as a computer simulation technique for modeling and analyzing the effect of the part or model built. This tool is very crucial to rectify the structure failure before manufacturing and test is carried on [17]. It is definitely vital to certify that the prevailing finite element model that was created during design process is a reliable model and able to provide accurate prediction of structural behaviour and performance before the genuine structure experience mass production in manufacturing area [18]. FE stands as the most suitable tool for numerical modeling in structural engineering as it is having ability of handling complex structural geometry, large complex assemblies of structural components and can build many different types of analysis [19]. This method of analysis becomes one of top crucial analysis in structural dynamics analysis. This method of analysis becomes one of top crucial analysis in structural dynamics analysis.

In order to get the most accurate result from the analysis, there are numerous existing factors which need to take an observation such as the type of element used, number of elements used, accuracy of geometric modeling, simulation of actual constraints, loading and boundary conditions [20]. The finite element analysis of a structure entails a modeling of fastener joints which connecting either composite parts, metallic parts, or amalgamation of these two materials [21] . Analysis is extends by choosing required type of joints to connect those two material declared earlier. Three joining methods are chosen which are RBE2, CBAR and CWELD which have dissimilar properties to each other.

3.1. Equivalence

Equivalency in model is conducted frequently in order to remove any coincides nodes and elements in a structure besides to keep the rigid connectivity in joining dissimilar plates together as explained in Figure 4. For a structure with a multiple surfaces, applying equivalence in analysis is unavoidable in order to connect meshes [22]. Besides, equivalence is needed in order to abolish the redundant nodes generated by meshing each surface independently [23, 24]. In this simulation, there are 168 nodes were eliminates due to the redundancy in the model and highlighted point of nodes can be seen in Figure 5 below.

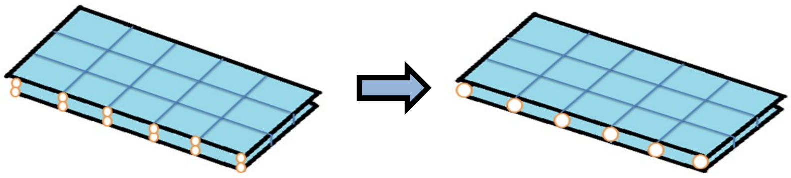

Figure 4. Equivalence.

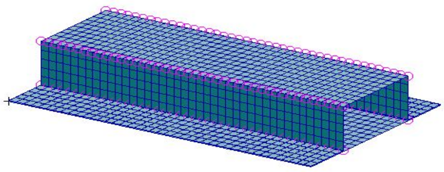

Figure 5. Eliminated nodes.

3.2. RBE2

RBE is an acronym stands for Rigid Body Element and RBE2 is a kind of formulation which consists of one independent node and one or more dependent node as shown in Figure 6, that does not have mass contribution [20, 25]. Rigid body using independent degree of freedom (DOF) at one grid and dependent DOF at an random number of grids called RBE2 [22]. These elements rigidly weld multiple grids to other grid. The independent and dependent term at the required nodes and joint must be considered. All dependent nodes of RBE-2 are coupled with independent nodes located at the specified location which resemble the spot weld points with total of 10 points each side in translation x-axis (Ux), translation y-axis (Uy), translation z-axis (Uz), rotational x-axis (Rx), rotational y-axis (Ry) and rotational z-axis (Rz) directions. Figure 7 shows the RBE2 connector of top hat structure, with total 20 RBE2.

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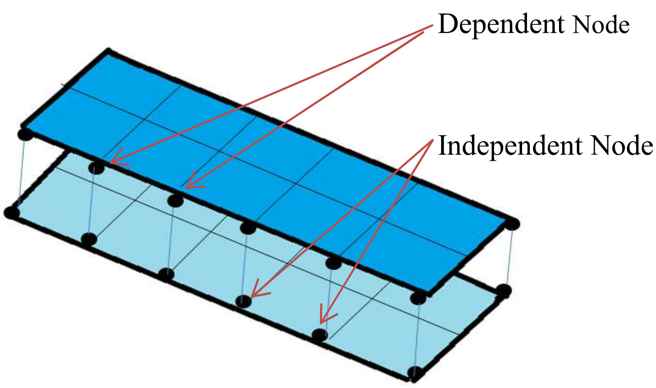


Figure 6. RBE2 with dependent and independent joints.

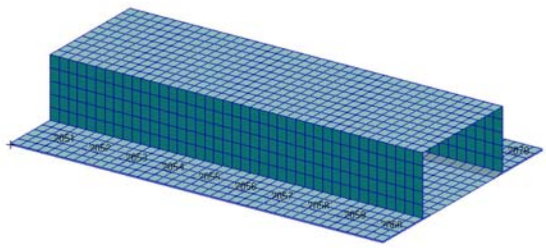


Figure 7. RBE2 element in top hat structure

3.3. CBAR

CBAR element is one example of joining provides in MSC Patran that able to withstand various kind of loads such as tension, compression and also bending forces. In the simulation, bar element is declared as a form of properties for curve [26]. Bar is responsible to joined two plates together at node location as displayed in Figure 8 below. The diameter for bar is 0.001m and its geometrical properties which is Young Modulus and Poisson ratio had been set to 1000 GPa and 0.27 respectively. The reason why Young Modulus of CBAR is declared much more higher than material is to represent the rigidity of welded joint. Figure 9 shows total of 20 CBAR elements top hat structure.

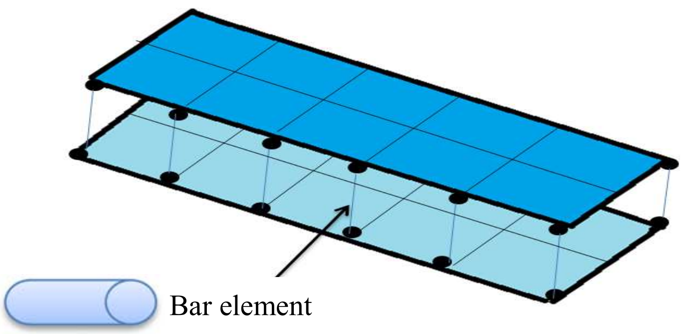


Figure 8. CBAR.

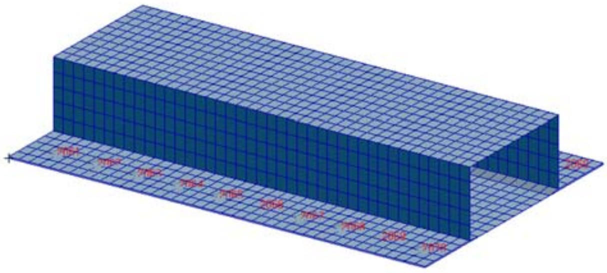


Figure 9. CBAR element in top hat structure.

3.4. CWELD

Weld connector, CWELD is a type of joining in which is extensively picked and utilized in modelling spot welds especially for Resistance Spot Welding process and finite element analysis due to goodness in flexibility in the type of mesh and ability to be update the element in model updating. Among three different connection types which is point-to-point, patch-to-point, and patch-to-patch connection [27, 28], the most versatile and frequently chosen in structural dynamic is the third one as displayed in Figure 10 below. In this paper, the connection is made up by connecting patch from upper element with corresponds lower element by choosing specified connecting node. The property of CWELD element is defined in welding properties (PWELD) entry. The property parameters are the material identification number and the diameter D of the spot weld. The diameter of spot weld is set to 0.001m with range length to diameter ratio between 0.2 to 5. If the diameter is larger than the surface patch, the spot weld element may underestimate the stiffness of the connection. Figure 11 shows how CWELD is modelled in top hat structure.

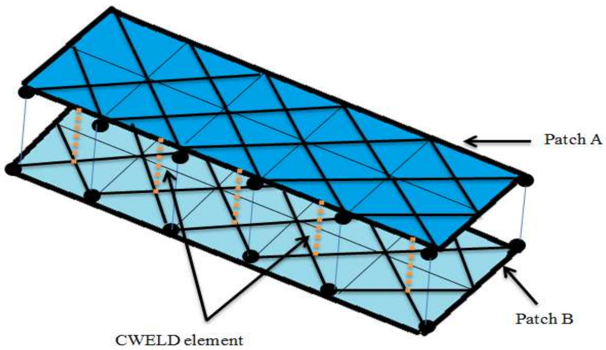


Figure 10. CWELD element.

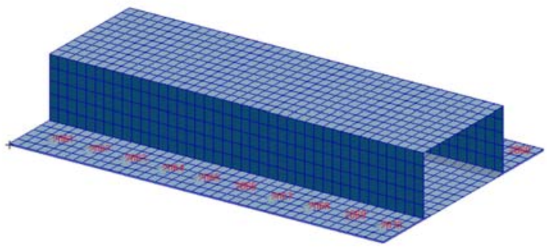


Figure 11. CWELD element in top hat structure.

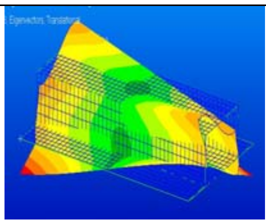
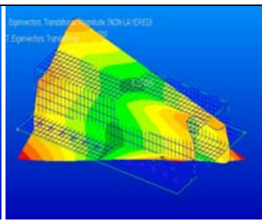
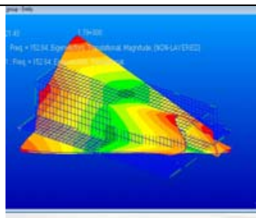
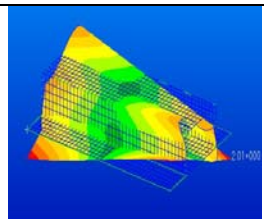
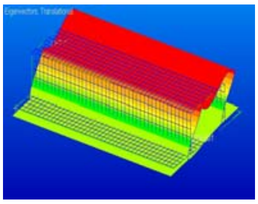
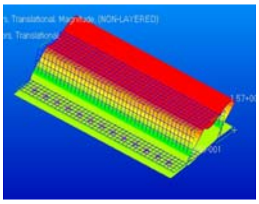
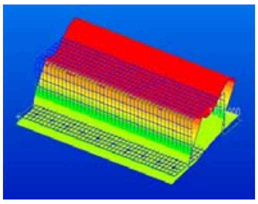
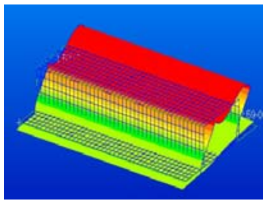
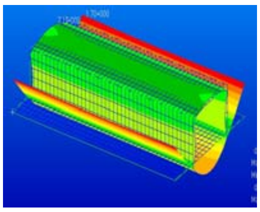
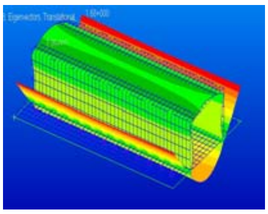
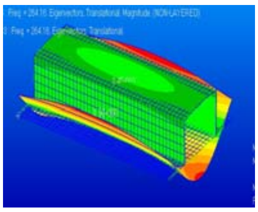
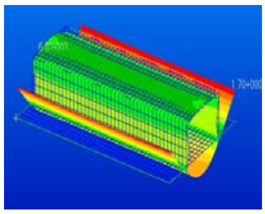
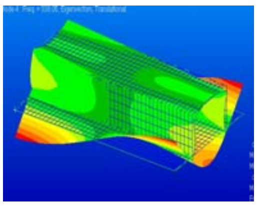
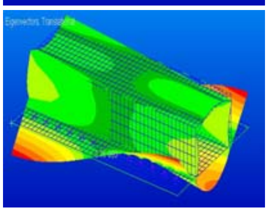
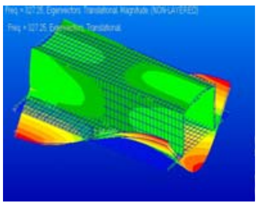
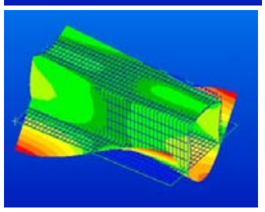
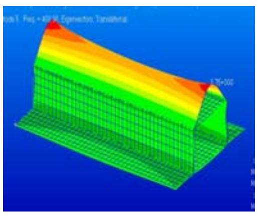
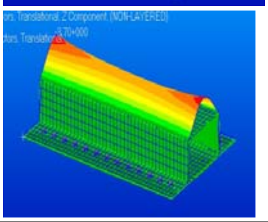
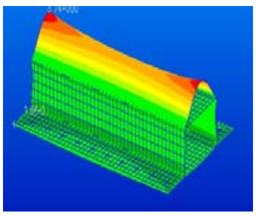
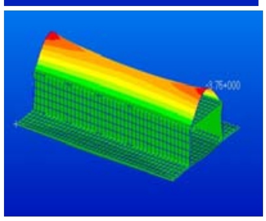
4. Results from FEA

After conducting the joining process, the result is analysed and they are differ to each other which prove that joining method strongly affect the dynamic behaviour of structure. Natural frequencies which can be defined as a frequency at which a system tends to oscillate in the absence of any driving or damping force are acquired from simulation along with mode shape which is an illustration of a structure at certain frequency. From the simulation, there are bending, torsion and both in the structure for each mode shapes. Tabulated results can be seen in Table 2 and Table 3 below.

Table 2. Natural frequencies of top hat structures.

Mode	Natural Frequency (Hz)			
	Equivalence	RBE2	CBAR	CWELD
1	175.58	177.87	175.68	175.60
2	253.14	253.15	253.14	253.14
3	278.14	279.88	278.26	278.19
4	338.05	342.29	338.72	338.21
5	408.98	409.08	409.00	408.99

Table 3. Mode shapes of top hat structures.

Mode	Mode Shape			
	Equivalence	RBE2	CBAR	CWELD
1				
2				
3				
4				
5				

5. Discussion

Regarding joining strategy in this study, all connection types can be modelled when compatible mesh was applied to the structure [22]. Three types of connecting elements are compared with a purpose to select the most reliable to resemble rigid joined between material which is assumed as equivalence rigid body connection. Errors might be as a result of the improperly declaring materials properties such as Young's Modulus, density or Poisson ratio. Based on comparison of natural frequencies with different joint structure in Table 4, it is clearly seen that CWELD offered the lowest percentage of errors as it is closely resembling rigid body connection with almost similar mode shapes. In this paper, the diameter is set to be less than surface patch to prevent underestimation of connection stiffness. Result gained indicates that CWELD joining almost nearly reached rigid body connection with only 0.016% errors while RBE2 and CBAR are failed to gives lower percentage errors.

Table 4. Comparison of natural frequencies with different joint structure.

Mode	Equivalence	RBE2	Error (%)	CBAR	Error (%)	CWELD	Error (%)
1	175.58	177.87	1.300	175.68	0.057	175.60	0.011
2	253.14	253.15	0.004	253.14	0.000	253.14	0.000
3	278.14	279.88	0.626	278.26	0.043	278.19	0.018
4	338.05	342.29	1.254	338.72	0.198	338.21	0.047
5	408.98	409.08	0.024	409.00	0.005	408.99	0.002
Total Average Error			0.642		0.061		0.016

6. Conclusions

This effort has examined some of the FE models developed to represent spot welds normally produced by RSW in the past. In between all these models, CWELD is chosen to model the spot welds. Generally, the aim of this study is to investigate some methods on modelling joined in order to estimate the dynamic behaviour. Three types of connection modelling which is RBE2, CBAR and CWELD are chosen and trustworthiness of these three joining were compared as referring rigid body connection which become as benchmark in calculating errors. RBE2 is less preferable for the future study due to the disability in model updating. In a nutshell, for joining resistance spot welding in dissimilar material plates, CWELD joining is the most reliable to be nominated due to its most exactly prediction of mode shapes and less total average errors in natural frequencies for all modes.

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