The Influence of Spot Weld on The Stiffness of a Car Body T-Joint

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Abstract. The stiffness of the car body becomes important due to the fact that it must keep the passenger’s compartment undeformed even during severe operating conditions. Car body T-joint is one of the main parts of car’s body to properly support its function. Three different cases were applied to evaluate the influence of difference spot weld configuration to bending and torsional stiffness of car body T-joint. The stresses and the displacements were also deeply investigated. The maximum stress in longitudinal direction and due to moment reaches its peak on 55x15 spot weld configuration. The displacement increases as the spot weld distance widen. Both bending and torsional stiffness decrease as the spot weld distance becomes larger.

1. Introduction
One of the purposes of body design is to achieve structural function, which is to support the vertical force due to the weight of the occupants as well as the mechanical components required for vehicle propulsion, control and other system [1]. Therefore, it endures mechanical stresses from several sources. The main frames surrounding the passenger cabin are, in fact, essential to reduce the possibility of passenger’s injury in the case of impact from all three directions and due to rollover [1]. The main tasks are to maintain the passenger’s compartment as rigid as possible in case of crash and to absorb the crash energy exerted on the vehicle on specific impact condition by means of the structure protruding from the compartment. Therefore, the frame of the passenger compartment of the vehicle must be very stiff, whereas the deformable structures with appropriate absorption characteristics must also be taken into account. The practical technology available for the construction of the car body is by means of spot welds. In this case, the stiffness and deformation on the assembly due to the spot weld sequence become obviously crucial. In fact, approximately 80% of failure of automotive components occurs at or in the surrounding of the spot welds [2]. Car body T-joint in this study refers to the bottom section of B-pillar zone of vehicle body, in which the continuous hinges of rear doors and the front seat safety belts are fitted.

Considering the important aspect of automotive body structures, a number of studies has been conducted in order to investigate its mechanical properties. Koricho et al. [3] conducted an experimental test and finite element investigation of the bending behaviour of composite joints in vehicle. The experimental results on the effect of the manufacturing process and experimental setting on the load-carrying capacity and failure mode of joint was deeply investigated. An approach to
evaluate the structural performance of a vehicle model in terms of the joint stiffness was also conducted by Kiani et al. [4]. The effect of the joint stiffness on the full and offset frontal impacts as well as the vibration characteristics with respect to the joint modulus which were adjusted was examined. Sharman [5] investigated the effect of joint flexibility on the torsion of a vehicle body. The comparison between the tested stiffness and theoretical approximation was clearly studied. The mechanical behaviour of simplified T-joint for a car body B-Pillar made with composite material has also been investigated [6]. However, this work chiefly investigates the car body T-joint that is at the lower extremity of the B-pillar zone by using steel material [7]. The method of finite element modelling has also been utilized to predict equivalent stiffness of 3D space frame structural. The use of circular beam has been chosen by researchers [8]. The aim of the paper is to study the influence of the different configuration of the spot welds on the bending and torsional stiffness of a car body T-joint. The calculation on the maximum equivalent stresses due to three cases of the loads and their relative and rotational displacement are also investigated.

2. Numerical Analysis Method and Description

2.1 Model Description

The finite element method becomes preferable choice since it can be used to simulate extremely complicated shapes [9]. This methodology has been chosen among several proposed methodology from other researchers including the optimization automotive body joints [10], [11]. The car body T-joint consists of two main components which are the joint and the plate. One of the references of the geometry of the model is adapted from Ref [3]. The overall length of the model is 338 mm, the overall wide is 384 mm, the height is 39.9 mm and the thickness is 1 mm. Considering the overall dimension of the model, the shell properties is the most appropriate option for the definition in the simulation. The generated mesh is the combination between quads and trias mesh with the size of the element of 5 mm. Further, element check is necessary to perform in order to yields the proper approximation of the results. The steel material is chosen for the definition of the material. The young’s modulus is defined as 2100 MPa, the poisson ratio is 0.3, and the material density is 7.8e-9 Gkg/l. The simplified model of the car body T-joint is deployed in Figure 1.

The welded joints represent one of the most important tasks in car body finite element method model definition. The finite element method is also possible to evaluate the stiffness of a car body by means of adhesive joints [12]. Nodes of the elements to be joined can be merged or joined with ID elements. In this work, the welded joints are simulated with rigid elements by using semi-automatic command spotweld provided by the solver. The welded points are positioned on the middle line of the fins with the distance of 25 mm, 35 mm, 45 mm, 55 mm, 65 mm, and 75 mm. In all spot weld configuration, the offset is defined by 15 mm (Figure 1 (c)). The loads are applied in the extremity of the upper arm of the joint, while the constraints lock the degree of freedom of the other two ends (Figure 1 (a)). Loads are applied to a master node linked to the nodes of the extremity cross section of the slave nodes. Three cases are applied in this study. Case A applies the force in X and Z direction with the value of 500 N and moment with respect to Y axis 5000 N.mm. Case B exerts the force 1000 N in both X and Z direction, while the moment is 10000 N.mm with respect to Y. Case C imposes the force 1500 N in X and Z direction and moment 15000 N.mm in Y axis. The constraints are applied directly to the nodes of the extremity cross section (Figure 1(a)). Von Mises stress approximation is chosen to represent the maximum equivalent stress of the results.
2.2 Governing Equations

In order to calculate the bending stiffness of the T-joint, we consider a cantilever beam with a force on the extremity of the beam. Considering the applied load $P$, the length of the beam $I$, young’s modulus $E$, and second moment of area $I$, the maximum displacement $\delta_{\text{max}}$ is defined as

$$\delta_{\text{max}} = \frac{Pl^3}{3EI} \quad (1)$$

and the bending stiffness $K$ can be expressed as

$$K_{\text{bending}} = \frac{3EI}{l^3} \quad (2)$$

In other words, we can calculate the bending stiffness of the T-joint by dividing the applied force $P$ which are in X and Z direction to the resulted displacement in each direction. Considering the torsional stiffness in rectangular cross section, the maximum stress occurs in the middle of the longer sides of the rectangular $h$ and zero in the centroid and in corners. The maximum stress per length of a beam is

$$\tau_{\text{max}} = \frac{M_t}{W_t} \quad (3)$$

$$W_t = ab^2h \quad (4)$$

where $M$ is the applied moment, $b$ and $h$ are the shorter and the longer side of the rectangle, $a$ is the numerical factor depending upon the ratio of $h$ and $b$. The angle of twist per unit length $l$ is

$$\theta = \frac{M_t}{GI_t} \quad (5)$$

$$K_{\text{torsion}} = \frac{GI_t}{l^3} \quad (6)$$

where $G$ is the shear modulus of the material. The calculation approach of the torsional stiffness is based on the rotational displacement measured in the extremity where the loads are applied. In other words, by knowing the relative displacement in Z direction of the node A and node B (Figure 1(b)) and knowing the distance between two nodes, the angle of the rotational displacement can be calculated. Therefore, the result of torsional stiffness can be approximated.

3. Result and Discussion

3.1 Stress, Displacement and Bending Stiffness in X Direction

The unavoidable effects of the use of spot weld to combine two materials to obtain desired stiffness in the degradation of the joint stiffness under high mileage [13]. The mentioned probability is true, yet it still needs to obtain the most appropriate joint stiffness in the first stage of the production. Moreover, the stiffness of a car body can also affects in the concept design phase [14]. In this case, the investigation is focused on the effect of the applied force in X direction with respect to the reference frame, representing the force in the longitudinal direction experienced by the car. Due to this force, the maximum displacement occurs in the end point of the T-joint, in which the rigid-web structure is created to apply the loads. The values tend to decrease to the part approaching to the applied constraints. The representation of the displacement is depicted in Figure 2 and the detail of the displacement for each case is shown in Figure 5.

Among six chosen spot weld configurations, the maximum equivalent stress occurs for the 55x15 spot weld configuration (Figure 4). The case C reaches maximum equivalent stress of 293.8 MPa, the case B has the peak in the value of 195.9 MPa and merely 97.94 MPa for case A. It can be inferred that by imposing 1500 N of force in X direction (case C) could generate the higher increment of the stress for the first-four consecutive spot weld configurations. The further spot weld configurations, which are 65x15 and 75x15, the trends of the stress undergone by the joint is decreasing. As far as the displacement is investigated, the bigger distance of the spot weld effects in the increment of the displacement of the T-joint for the same given load. Further detail on Figure 5, for the 25x15 weld configuration, the displacements are 0.1063 mm, 0.2126 mm and 0.3188 mm for 500 N, 1000 N and
1500 N applied force respectively. In each case, the trend of the increment value of the displacement is relatively linear compared to each other. The 75x15 weld configuration gives the highest displacement value. For this case, the 500 N of force in X direction yields in 0.1193 mm of displacement, 1000 N of force results in 0.2387 mm displacement and 1500 N of force gives 0.3580 mm of displacement of the model in X direction. Therefore, considering the applied force and the resulting displacement, the bending stiffness in X direction can be calculated. Recalling the equation (2), the results of the bending stiffness in X direction tend to decrease as the spot weld distance becomes larger (Figure 3). 25x15 spot configuration gives the value of bending stiffness in the order of 4703 N/mm. The 35x15 weld configurations yields 4603 N/mm stiffness. Further having larger spacing of the weld configuration gives the value of the bending stiffness 4471 N/mm, 4405 N/mm, 4310 N/mm, 4190 N/mm of the 45 mm, 55 mm, 65 mm and 75 mm spacing distance of the spot weld respectively.

Figure 2. Representation of the displacement in X.

Figure 3. Bending stiffness in X direction.

Figure 4. Stresses due to force in X direction.

Figure 5. Displacement in X direction.

3.2 Stress, Displacement and Bending Stiffness in Z Direction

The load in Z direction represents the case in which the vehicle is imposed a load in the lateral direction. The bending stiffness considerably decrease as the spot weld pattern wider. However, it has been studied by previous researcher that structure with spotwelding and adhesive bonding altogether is better than one with only spotwelding for static bending load [15]. The spot weld configuration of 25x15 gives the highest bending stiffness of the car body T-joint which has value in the order of 34.89 N/mm. Increasing value of the spot weld distance decreases the value of the bending stiffness for the further case of the spot weld which is depicted in Figure 7. The longest distance of the spot weld space which is 75x15 has the lowest value of the bending stiffness of 33.41 N/mm. Figure 6 represents the
displacement due to the force in Z direction. Three forces are applied to the model and it gives the different displacements. It is obvious that the more the force imposed in the T-joint, the more the displacement experienced by the model (Figure 9). Furthermore, when the stress is further studied, the pattern of the stress is similar to the displacement stress which also increases as the spot weld configuration is wider (Figure 8). The lowest stress of the Case A is experienced by 25x15 weld configuration which has the value of 1920 MPa. It increases as the spot weld is wider. For 75x15 spot weld configuration the stress value becomes 1985 MPa. The similar trend also occurs in the case B and case C for the maximum equivalent stress. The minimum one is 3840 MPa for 25x15 and the maximum is 3970 MPa for 75x15 spot weld configuration in case B. For the case C the stress 5760 MPa is for the configuration 25x15 and 5954 MPa for 75x15 spot weld configuration. The highest relative displacement due to the force in Z direction is represented in the Figure 9. It can be observed that the displacement mostly occurs maximum in the point in which the loads are applied. For 500 N applied force, the 25x15 spot weld configuration yields the maximum displacement of 14.33 mm, while for 75x15 results in 14.96 mm. When the force of 1000 N is applied in Z direction, the displacement is 28.66 mm and 29.92 mm for 25x15 and 75x15 spot weld configuration respectively. Case C has the displacement in Z direction of 42.99 mm when the lowest spot weld distance is applied and 44.89 mm for the widest spot weld distance is generated. Those three trends occur in a similar trend which slightly increases as the spot weld wider.

![Contour Plot](image1)

**Figure 6.** Representation of displacement in Z direction.

![Bending Stiffness in Z Direction](image2)

**Figure 7.** Bending stiffness in Z direction.

![Von Mises Stress - Bending in Z](image3)

**Figure 8.** Stresses due to force in Z direction.

![Relative Displacement in Z](image4)

**Figure 9.** Displacement in Z direction.
3.3 Stress, Rotational Displacement and Torsional Stiffness about Y Axis

Torsional stiffness becomes concern due to the fact that it is also possible that the car body T joint would undergo the torsion in case the crash happens from the lateral and longitudinal side. This joint stiffness analysis has also been investigated for enhancing the structural design and performance of a vehicle [4]. The torsional stiffness is related to the applied moment and the rotational displacement experienced in the model which has been explained in the Equation (5). Three different moments are applied in the model in order to verify the results in terms of the stress, rotational displacement and torsional stiffness. The prominent point in this case is that the trend of the stress experienced by the model reaches the peak in the pattern of the spot weld configuration of 55x15. Initially, the trend relatively rises in the first three spot weld configurations and, after this point, the value considerably increases and reach a peak before going down in the last two spot weld configurations (Figure 12). Figure 13 shows the increase pattern of the rotational displacement. Three cases show the linearly increased trend of the rotational displacement caused by three different applied moments (case A, case B and case C).

The wider the spot weld distance gives the higher rotational displacement of the car body T-joint.
For 5000 Nmm moment applied, the narrowest spot weld has rotational displacement of 0.0140 degree, while for the highest rotational displacement is 0.0189 degree experienced by the 75x15 spot weld. The pattern is quite similar for two other cases. The narrowest spot weld (25x15) yields the rotational displacement of 0.0295 degree (case B) and 0.0443 degree (case C) while for the widest spot weld configurations (75x15) are 0.0378 degree (case B) and 0.0567 degree (case C). As such, the final torsional stiffness can be calculated based on the distance between node A and B and the relative rotational displacement experienced by each case. The result of the torsional stiffness evaluation is deployed in Figure 11. The highest torsional stiffness of the model is achieved when the 25x15 weld configuration is applied. The value of the highest torsional stiffness for this configuration is approximately $35.46 \times 10^4$ Nmm/deg. Further widen the spot distance reduces the torsional stiffness of the joint as depicted in the Figure 11, which are $32.16 \times 10^4$ Nmm/deg, $30.07 \times 10^4$ Nmm/deg, $29.20 \times 10^4$ Nmm/deg, $27.86 \times 10^4$ Nmm/deg, and $26.44 \times 10^4$ Nmm/deg for 35x15, 45x15, 55x15, 65x15, and 75x15 spot weld configuration respectively.

4. Conclusion

Having wider distance of the spot weld gives the lower value of both bending and torsional stiffness. The stress experienced by the T-joint reaches the maximum value when the spot weld pattern 55x15 in both due to bending in X direction and due to the moment about Y, while the maximum stress for the bending in Z direction occurs in the 75x15 spot weld configuration. Both relative displacement and torsional displacement increase as the distance of the spot weld larger. The results could become one of the references to consider the appropriate spot weld configuration of the car body T-joint, so that in the end, proper mechanical properties of a car could be achieved. Future works are to study and compare between the simulation results and experimental result and also to investigate the effect of the different materials.

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