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Three-dimensional Finite Element Analysis of the Front Cross Member of the Peugeot 405

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***Abstract*—**Undoubtedly, chassis is one of the most important parts of a vehicle. Chassis that today are produced for vehicles are made up of four parts. These parts are jointed together by screwing. Transverse parts are called cross member.

This study reviews the stress generated by cyclic laboratory loads in front cross member of Peugeot 405. In this paper the finite element method is used to simulate the welding process and to determine the physical response of the spot-welded joints. Analysis is done by the Abaqus software.

The Stresses generated in cross member structure are generally classified into two groups: The stresses remained in form of residual stresses after welding process and the mechanical stress generated by cyclic load. Accordingly the total stress must be obtained by determining residual stress and mechanical stress separately and then sum them according to the superposition principle.

In order to improve accuracy, material properties including physical, thermal and mechanical properties were supposed to be temperature-dependent. Simulation shows that maximum Von Misses stresses are located at special points. The model results are then compared to the experimental results which are reported by producing factory and good agreement is observed.

***Keywords*—**Chassis, cross member, residual stress, resistance spot weld.

I. Introduction

So many studies have already been done to increase chassis strength and fatigue life. These studies led to increase in life and strength and reduction of weight of chassis by the change in chassis design. This trend has changed some front parts of an auto-body from a single simple shell structure to an integrated multi- shell structure.

Previously, chassis includes a frame composed of longitudinal and transverse beams, while the focal chassis have different structure. Transverse beams are replaced with the cross members made up of shells and are screwed with the longitudinal beams instead of the welding so that more flexibility has been provided for chassis and the fracture phenomenon in welds, joining the beams is removed. Also the weight reduces when the multi-shell structure is utilized. Because of their lower weight and higher strength of cross members, their usage has increased.

In this paper the maximum Von Misses stress is estimated in front cross member of Peugeot 405 and the critical regions will be determined. Resistance spot welds play an important role in structure strength and fatigue life of cross member. The integrity and strength of automotive structures are often dependent on the strength of their spot weld joints. As a result, we focus on different aspects of the spot welding process.

Simulation of resistance spot welding processes have been studied and developed by numerous researchers. According to the literature there are several models and approaches for modeling welding processes. For instance; Lindh and Tocher (1967) investigated the heat generation and development welding residual stresses during resistance spot welding process and they found that residual stresses in Ti–8Al–1Mo–1V haven't great dependency on electrode force. Nied (1984) introduced an electrically, thermally and structurally coupled axisymmetric model considering temperature-dependent properties and Joule heating. The displacements and stress distribution of the electrode and workpiece were illustrated. Cho and Cho (1989) developed a theoretical basis for thermal behavior of resistance spot welding. Finite difference method was used to estimate the temperature distribution of nugget during the welding process.

Wei and Ho (1990) developed a three-dimensional transient heat transfer model to predict temperature distribution during resistance spot welding. Anastassiou et al. (1990) studied residual stress distribution and microstructural changes in a steel sheet and also investigated the relationship between welding parameters and fatigue behavior. They found that residual stresses have maximum magnitude in the weld center and are reduced towards the nugget edge.

Tsai et al. (1992) presented an expansion-based control algorithm for resistance spot welding. The finite element method was used to determine the physical response of the nugget material for different welding conditions. The temperature-dependent mechanical and thermal properties were taken into account. Nugget growth was presented under various welding condition.

II. Modeling and Analysis

A. Review

As mentioned before, in this study the front cross member of Peugeot 405 which has sixteen shells and four bushes are considered. These shells are jointed by the ninety resistance spot welds in certain position. The load equal with 4.4KN is applied in form of sinus diagram by frequency of three in second and with 45 degree angle to the symmetry axis of cross member. This load is affected on a triangular part between the

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cross member and the force inducing machine.

The cross member, the triangular part and the force inducing machine are shown in Fig. 1.

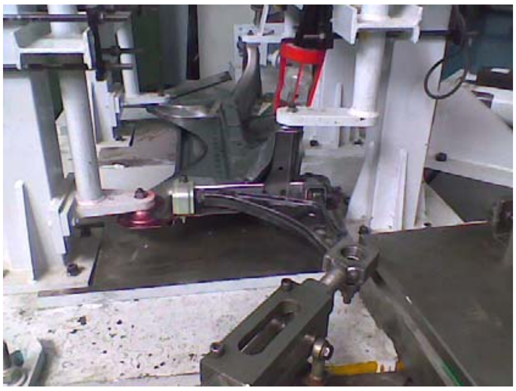


Fig. 1 Cross member, the triangular part and the force inducing machine

The cross member is constrained in four points by a constraint set so that it provides the best conditions for the simulation. Material of cross member is st-12 which is widely used in automotive industry. Elastic modulus and Poisson coefficient of this alloy are 290 MPa and 0.3 respectively at the room temperature. The elements in this alloy are shown in Table I.

To obtain total stress it is necessary to perform two separate analyses on the cross member. One of these analyses is performed to estimate residual stress and the other is carried out in order to estimates the stress caused by the mechanical load. Afterwards they're summed up to determine the total stress.

B. Residual stress

Spot welds, is a frequently used technique to fabricate sheet metal structures. The process involves joining two or more pieces of sheet metal in localized areas. This process is typically used to obtain a lap joint of sheet metal parts.

TABLE I
CHEMICAL COMPOSITION OF MILD STEEL ST-12

C	Mn	P	S
<0.12%	0.3-0.5%	<0.03%	<0.05%

The resistance spot welds are used widely in industry due to its advantages such as its fast and clean process and low expenses, but because of the generation of residual stress and distortion and fine cracks among plates, the strength of structure decreases somewhat and when cyclic forces are applied to the structure, these defects can spread and intensify the fatigue phenomenon. Among the weaknesses mentioned, residual stress has special importance because it is often in form of tensile stress and increases the speed of growth of the cracks and decreases the fatigue life, Since the tensile stresses open the cracks.

The most important factors that affect the amount of residual stress in spot welds are heat input, welding time, mechanical and thermal properties of metal welding and the speed of cooling process. Since thickness of shells are different, the spot welds of the cross member are classified into four main groups based on sheet thickness and nugget diameter, heat input and welding time. As a result, four groups of specimens are considered. Thickness of shells, nugget radius and current intensity are applied to each of the specimens, are shown in table II.

Specimens with equal dimensions of 40mm×60mm were provided. Specimens have 20mm overlapping for welding. The distance between workpieces is .1mm.

In the resistance spot welds with the using of heat and pressure, two sheets can be joined. The Increase in the temperature is provided by passing the electricity. The amount of energy that generated in each of the spot welds, can be expressed by Joule's law:

$$Q = RI^2 t \quad (1)$$

Where I is the electrical current, R is electrical resistivity, t is welding time and Q is the generated heat.

TABLE II
PROPERTIES OF SPECIMENS

Specimens	Radius of nugget(mm)	Thickness (mm)	Weld current(KA)
First group	1.75	1.7	3.5
second group	2.65	2	4.5
third group	3.5	3	4.5
fourth group	3	2	4.5

Rate of applied thermal energy in form of the volume flux and welding time for each specimen is shown in Fig. 2. In a separate analysis the volume flux is applied to each of the specimens. It is also assumed that no preheating process is performed. The preheating step is performed to decrease the effect of surface conditions, such as pollution and roughness. The maximum temperature of the workpiece does not rise over the melting point at the preheating step. Accordingly, the welding conditions at this time have little effect on the residual stress. Also considering these parameters are not possible by the software, so this step is ignored in the analyses [1].

Two steps are defined for each of the analysis. In the first step the thermal load was applied. Duration of the first step is equal with the welding time. In the second step there is no load. In this step because of the thermal conductivity and convection the nugget temperature decreases and the residual stress remains in the shells due to temperature gradient. Minimum time needed for the second step must be of the scale that the temperature of the sheets can decrease to the room's temperature.

These analyses have a strongly nonlinear tendency due to the contact elements, the temperature-dependent properties, and the plasticity and if the time increment is not small enough, large errors will occur in the calculated stresses [1].

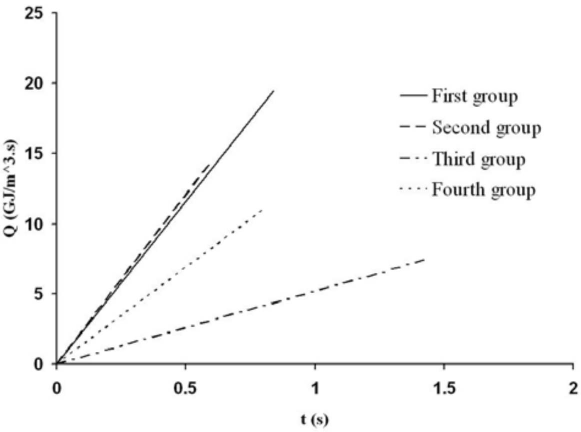


Fig. 2 rate of applied thermal energy and welding time in each of specimens

The conditions of weld cooling include a static air around the spot weld. In this case Convection coefficient is between 5 and 20 W / m^2K°. Convection coefficient is assumed to be 15 W / m^2K° in the present study.

Since the surface temperature is increasing to the high temperature for a short time, the role of radiation heat transfer mechanism is small, therefore this mechanism has a little effect both on temperature distribution and residual stress, As a result it will be ignored [2].

Since this type of analysis is thermal elasto-plastic, in addition to mechanical properties such as elastic modulus, Poisson coefficient and plastic modulus the thermal properties such as thermal conductivity, heat capacity and thermal expansion also are required. These properties directly affect the amount of stress and distortion of the sheets. Also how these properties changes in respect to temperature is shown in Fig. 3 [3].

The remained residual stresses after welding process are shown in table III.

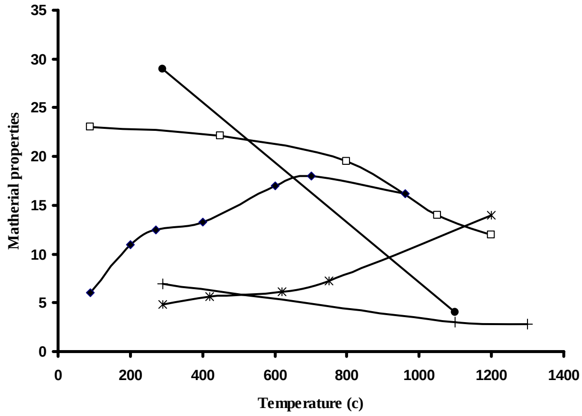
C. Mechanical stresses

As mentioned before, the cross member is composed of sixteen shells and four bushes. Different methods exist to joint the shells together. In an article published by the Deng, the different simulation methods are suggested for modeling multi-shell structures which are joined together with spot welds. In that paper five types of mechanical loads were applied to the specimens.

The evaluation was carried out based on comparisons of the structural stiffness of the joints. A detailed error analysis was provided. In that study the sheets and nuggets were simulated with the shell and solid elements subsequently. This method has the minimum structural stiffness error in compare to model reference [4].

TABLE III
GENERATED RESIDUAL STRESSES

Specimens	Von Misses stresses(MPa)
First group	98.6
second group	156
third group	187
fourth group	154



Symbol	Material Properties	Unit
●--σ_y	Yield stress	$\times 10^7$ Pa
□ ---E	Young's modulus	$\times 10^{10}$ Pa
◆ ---α	Thermal expansion	μ m/m ℃
+---k	Conductivity	$\times 10$ W/m ℃
* ---c	Specific heat	$\times 10^2$ J/Kg ℃

Fig. 3 Temperature-dependent properties of st-12

TABLE IV
GENERATED STRESSES DUE TO THE MECHANICAL LOADS IN THE CRITICAL POINTS

Critical points	Von Misses stresses(MPa)
Number(1)	236
Number(2)	225
Number(3)	204
Number(4)	202
Number(5)	180
Number(6)	135
Number(7)	112
Number(8)	90

After designation of the parts of cross member, they're merged with the Merge geometry method. Shell elements are of type S4R and nugget elements are C3D8R type. In order to have an accurate analysis, the refined mesh is assigned to the regions which are nearest to the point that the force is applied.

It is necessary to simplify the analysis due to the several parts and so many spot welds which is existing in cross member. Towards this goal, the triangular part and rubbers between this part and cross member are removed and the force components are applied directly to the cross member. This prevents from generation of the complexity in boundary condition.

As mentioned before the load equal with 4.4KN is applied in form of sinus diagram by frequency of three in second and with 45 degree angle to the symmetry axis of cross member.

Bushes are removed and the suitable boundary conditions are used instead, because the role of these bushes is prevention of bending and deformation of cross member in constraint points. In fact these bushes act as same as the boundary conditions which constrain the shells of cross member in certain directions. Since the transposition speed of force inducing point is low and the inertia and damping play less role, we will have a static analysis [5]. The amounts of mechanical stresses are shown in table IV. These points have more stress to other parts. Positions of these points are displayed in Fig. 4. These points are mostly next to boundary conditions or force inducing points.

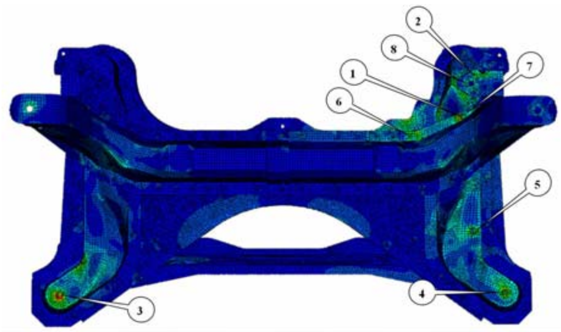


Fig. 4 situation of critical points

Finally, according to the superposition principle, residual stresses and mechanical stresses sum together and give the Von Misses stresses:

$$\sigma' = [\frac{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}{2}]^{.5} \quad (2)$$

Where σ' is the total Von Misses stress. Some of these points have only mechanical stress and some of the other points have the both mechanical and residual stress because of existence of spot welds in those positions. Total Von Misses stresses are shown in table V. As seen, the Von Misses stress in point number (2) is the highest.

III. Experimental Results

A kind of fatigue test is performed on the cross member in the producing factory. In this test, the cross member is subjected to one million cycle of load. The parts with crack lengths of less than 2 mm, are healthy. It's clear that all of the cross members are not tested and the test is done on just several cross members to assure safety of production process.

The factory reported only 1% cross members fail in this test. According to the experimental results the fracture has often been occurred in Points number (2) and (5) and (7). As it is observed there is a good agreement between the two sets of Results.

TABLE V
Total Von Misses stresses in the critical points

Critical points	Von Misses stresses(MPa)
Number(1)	162
Number(2)	215
Number(3)	204
Number(4)	202
Number(5)	180
Number(6)	149
Number(7)	182
Number(8)	209

IV. Conclusion

The spot welds of cross member have different nugget diameter and, sheet thickness, heat input and welding time. Therefore the spot welds are classified to four groups.

After simulation of four groups of spot welds in Abaqus software, thermal loads were applied to spot welds and suitable conditions for heat transfer were provided. After cooling, the residual stress remained in shells. The maximum residual stress was produced in third group. It may seem natural, because this group is subjected to thermal loads for a longer time.

In a separate analysis, mechanical load has been applied directly on the cross member. Maximum Von Misses stresses have been seen in the point number (2). According to the factory reports cracks often are generated in Points number (2) and (5) and (7) respectively. The analysis results performed with Abaqus, have a good agreement with the experimental results. This confirms the precision and accuracy of analysis. The results of this paper can be used in fatigue life prediction of the cross member in next studies.

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