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# Modeling and numerical simulation of the resistance spot welding of zinc coated steel sheets using rounded tip electrode: Analysis of required conditions

R.N. Raoelison [a,b,1,*], A. Fuentes [a], C. Pouvreau [a], Ph. Rogeon [a], P. Carré [a], F. Dechalotte [c]

[a] Université de Bretagne-Sud, EA 4250, LIMATB, 56100 Lorient, France
[b] Université de Technologie de Belfort Mo ntbéliard, LERMPS, 90100 Belfort cedex, France
[c] PSA Peugeot Citroën, Velizy, Route de Gisy, 78943 Vélizy Villacoublay cedex, France

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ABSTRACT

This paper investigates the essential conditions to improve the accuracy of a resistance spot welding computational study of advanced zinc coated steel sheets using rounded tip electrode. An experimental analysis is performed to highlight the required considerations for a suitable simulation. A sequential Electrical-Thermal-Metallurgical and Mechanical (ETMM) finite element analysis with appropriate precautions of the contact conditions enables to accurately simulate the nugget development during the welding. A critical smooth evolution of the contact radius is required. A fine meshing with an interfacial mesh size of at least $0.05 \times 10^{-3}$ m combined with a coupling time step of 0.0025 s between the electrical-thermal-metallurgical and the mechanical analysis allows a regular incrementation of the contact radius, without burdening the time computing. Accurate values of the contact resistance depending on the interfacial pressure and temperature are essential for a good simulation of the nugget size. The ETMM calculation is successfully extended to the simulation of the welding of a typical two sheets assembly.

## 1. Introduction

The Resistance Spot Welding (RSW) has always been the predominant assembling process in automotive industry. A vehicle body in white can contain up to 5000 spot welds. The weld is obtained by Joule effect. During the welding, a current with high intensity crosses through the assembly to be welded which are held between two electrodes with a predefined pressure. The heat produced in the assembly creates a molten zone giving a welded joint after solidification. The weldability depends on several parameters but the predominant ones are the physical properties of the constitutive material, the process parameters such as the squeezing force, the duration of the current, and foremost, the contact conditions including both shape and geometry of the electrode active face. These parameters are interrelated and interdependent making a long and expensive experimental study of the weldability. The numerical simulation has continually been a powerful tool to progressively reduce the important number of experimental tests. A current potential issue is to be able to predict the weldability of the high strength coated steels sheet using an accurate simulation with the interfacial phenomena which occur at both macroscopic and microscopic scale.

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* Corresponding author at: Université de Bretagne-Sud, EA 4250, LIMATB, 56100 Lorient, France. Tel.: +33 384583097.
*E-mail address:* rija-nirina.raoelison@utbm.fr (R.N. Raoelison).

[1] Current address: Université de Technologie de Montbéliard, IRTES-LERMPS EA7274, 90010 Belfort.

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**Nomenclature**

*Latin-script symbol*

| | |
|---|---|
| ECR | electrical contact resistance ($\Omega\,m^2$) |
| $f$ | yield surface (Pa) |
| $h$ | enthalpy ($J\,kg^{-1}$) |
| $J$ | current per unit of surface ($A\,m^{-2}$) |
| $k$ | coefficient of K.M. law (–) |
| $n$, $m$ | kinetic parameters of J.M.A. law (–) |
| $M_s$ | starting temperature of martensitic transformation (K) |
| $p$ | austenite proportion (–) |
| $p_A$ | residue of austenite at the temperature $M_s$ (–) |
| $p_i$ | proportion of the phase number $i$ (–) |
| $p_{\max}$ | maximal proportion of austenite (–) |
| $p_M$ | martensite proportion (–) |
| $P$ | pressure (Pa) |
| $Q$ | heat generation by Joule effect ($W\,m^{-3}$) |
| $r_{nugget}$ | nugget radius (m) |
| $R_p$ | isotropic hardening (Pa) |
| $th_{nugget}$ | nugget thickness (m) |
| $T$ | temperature (K) |
| TCR | thermal contact resistance ($K\,W^{-1}\,m^2$) |
| $U$ | displacement (m) |
| $V_1$, $V_2$ | voltage (V) |

*Greek-script symbol*

| | |
|---|---|
| $\alpha$ | share coefficient (–) |
| $\Delta t$ | coupling time step (s) |
| $\underline{\varepsilon}_i^{th}$ | thermal strain of the phase $i$ (–) |
| $\lambda$ | thermal conductivity ($W\,m^{-1}\,K^{-1}$) |
| $\Phi_g$ | heat flux generated in the ECR ($W\,m^{-2}$) |
| $\rho^{vol}$ | specific mass ($kg\,m^{-3}$) |
| $\sigma_1$, $\sigma_2$ | electrical conductivity of the medium 1 or 2 ($S\,m^{-1}$) |
| $\sigma^{él}$ | electrical conductivity ($S\,m^{-1}$) |
| $\sigma_{VM}$ | Von-Mises stress (Pa) |
| $\sigma_y$ | yield strength (Pa) |
| $\theta_1$, $\theta_2$ | temperatures at the interface of the media 1 and 2 (K) |

*Abbreviation*

| | |
|---|---|
| ETMM | Electro-Thermal-Metallurgical and Mechanical |
| JMA | Johnson–Melh–Avrami |
| KM | Koïstinen–Marburger |

*Subscript symbol*

| | |
|---|---|
| E/S | electrode/sheet interface |
| S/S | sheet/sheet interface |

At the macroscopic scale, there is a variation of contact surfaces due to the thermomechanical deformation of the assembly that governs the evolution of the current density in the assembly and the thermal exchanges between the sheets and the water-cooled electrodes during the welding. When using flat tip electrode, the mechanical features of the RSW are generally ignored according to a near stagnation of the initial contact surface [1–3]. With a rounded tip electrode, as the strong variation of the contact radius influences the nugget formation and growth [3,4], a calculation of this evolution is required in the simulation of the RSW.

At the microscopic scale, the contact between asperities generates a microconstriction of both current path and heat flux which in turn produces high level interfacial heating. Several computational simulations of the RSW accounting for the contact resistances using phenomenological models [5,6], empirical models [7,8], or experimental ex-situ or in-situ evolutions [9–11], agree that the consideration of the interfacial heating makes the simulation predictive. The Electrical Contact Resistance (ECR) causes an interfacial sparking effect that accelerates the heating of the assembly by the increase of the