COSTS CALCULATION FOR ELECTRIC RESISTANCE SPOT WELDING IN CAR BODY MANUFACTURING

Rasinac Mladen[*1], PhD student
Miodragović Tanja[*], PhD student
Ivanović Marina[*], Teaching assistant
Tešević Milan[**], M.Sc in Mechanical engineering

Summary: *In the automotive industry, resistance spot welding process is used for joining parts of the car body. Purpose of this paper is to see structure of costs in resistance spot welding and comparison of welding costs without and with expulsion of material. Since the series of car production is high, it is convenient to see how occurrence of expulsion influences on total welding costs of a car body.*

Keywords: *resistance spot weding, expulsion, costs*

Rezime: *U automobilskoj industriji, elektrootporni tačkasti postupak zavarivanja se koristi za spajanje delova karoserije automobila. Cilj ovog rada je da se vidi struktura troškova elektrootpornog tačkastog zavarivanja i poređenje troškova zavarivanja bez i sa istiskivanjem materijala. Kako su serije proizvodnje automobila velike, pogodno je da se vidi kako pojava istiskivanja utiče na ukupne troškove zavarivanja karoserije automobila.*

Ključne reči: *elektrootporno tačkasto zavarivanje, istiskivanje, troškovi*

INTRODUCTION

In resistance spot welding process, we have welded sheets which are set one above the other between electrodes (1), Figure 1. Throught the electrodes is passed direct or alternating current of high intensity. In the area of sheets contact (2) the temperature is rapidly increased, to a value above melting point. That is a consequence of high electrical resistance at that place. Due to the high resistance at point of contact, welded sheets are heated to the point at which it is generated liquid core, and under action of force (*F*) comes to joining of sheets. [1],[4],[5]

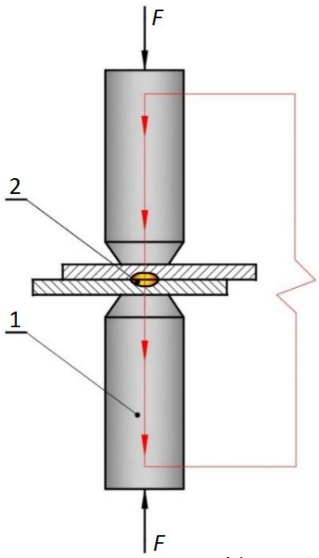

Figure 1. – Resistance spot welding proces. [1],[5]

**Faculty of Mechanical and Civil engineering, Dositejeva 19, 36000 Kraljevo*
[1] rasinac.m@mfkv.kg.ac.rs
***TURBO SERVIS, Miloša Obrenovića bb, 31000 Užice, Serbia*

Joining of sheets has three phases, Figure 2.

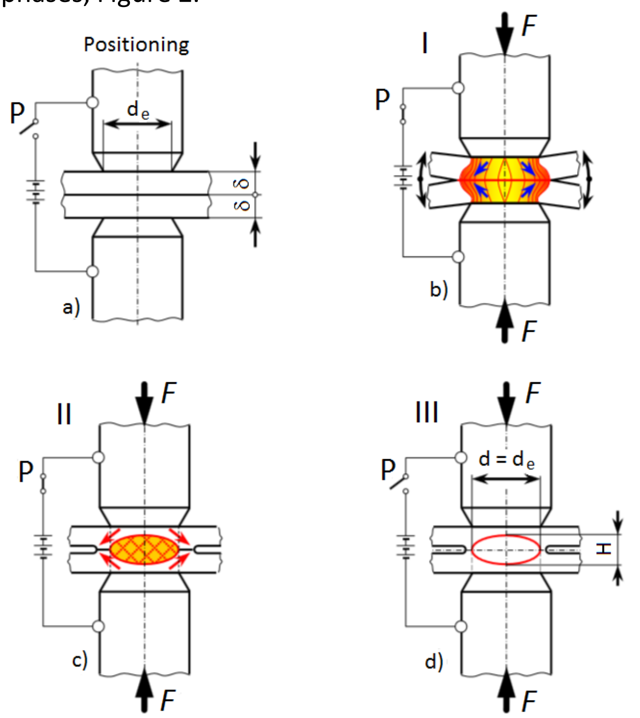

Figure 2. Phases of resistance spot welding. [2]

I phase starts with the flow of electrical current, with the intense heating and stirring of material.

II phase begins when the solidus temperature is reached. Temperature is higher on contact surface between two sheets.

III phase is cooling and crystallization of the molten core, which is the part of the welded sheets and has a variable volume.

Shape and dimensions of molten core depends on welding parameters, Figure 3.

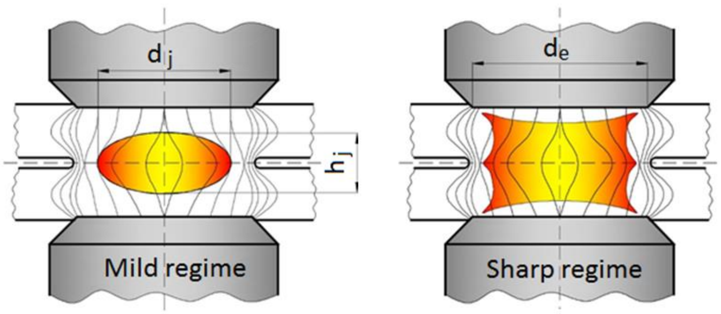

Figure 3. Influence of welding regimes on shape and dimensions of molten core. [1]

Using mild regimes, isoterms will have approximate shape of an ellipse, so that the molten core will have a shape of an ellipsoid. This regime has increased heat losses, beacuse considerably higher volume of material is heated, from the one that is needed. [1],[2],[3]

In sharp regime, process of welding will produce a much more complex shape of the isoterms and welded points. Peaks of the isoterms will have tendency to break trough to the surface of welded sheets in the contact zone between electrode and sheet. Also, they can break trough the zone towards the gap between

**Faculty of Mechanical and Civil engineering, Dositejeva 19, 36000 Kraljevo*
[1] *rasinac.m@mfkv.kg.ac.rs*
***TURBO SERVIS, Miloša Obrenovića bb, 31000 Užice, Serbia*

the welded sheets. In extreme cases, liquid metal will break trough the surface of sheets, and that is called expulsion. [1],[2],[3]

ELECTRICAL RESISTANCE AT RESISTANCE SPOT WELDING

During the spot welding, value of electrical resistance of the joint is constantly changing. Dependence of resistance over time can be obtained by experimental measurements. [1] The shape and structure of that dependence is shown in Figure 4.

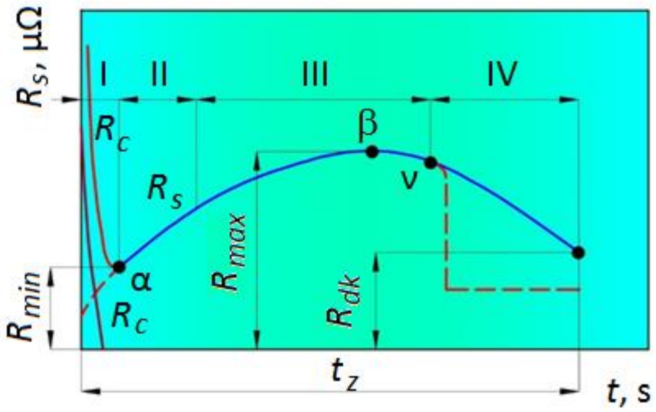

Figure 4. Curve of dynamic change of electrical resistance. [1]

Where the α denotes minimum of electrical resistance. At that point, value of contact resistance is zero. The point β is point of maximum resistance, and that corresponds to maximum amount of energy involved in process, and finally point ν represents moment of material displacement. [2],[3]

On the Figure 4. we can distinguish four different zones.

I – Establishing physical and electrical contact between welding details under action of force *F*, deformation of micro relief, increase of surface of local contact and decrease of contact resistance.

II – Initiation of the melting process in the area of contact surfaces of welded sheets.

III – It is characterized by three processes:

- increase of temperature in volume layers and increase of own electrical resistance,
- release of larger amount of heat which increases volume of molten core, and
- decrease of resitance of plastic deformation and to increase of dimensions of the coronary zone which currounds the core.

IV - Behind the β point there is a further fall of own resistance due to the continuaton of growth of dimensions of liquid core and plastic deformation. It is carried out on the basis of inertia characteristic processes i.e., latent heat. At some point, such thermal state of the surrounding ring is established, and mechanical properties that prevent the further growth of the core reach. This is the moment when the pressure of the liquid metal increased so much that it is greater then the tensile strength of the coronary zone and when there is high likelihood of expulsion. If the expulsion is reached, liquid metal breaks into the gap between the welded sheets and further into the surrounding space, that is, the liquid metal pierces the surface of the welded sheets around the contact area between sheets and electrodes. [1],[2],[3]

**Faculty of Mechanical and Civil engineering, Dositejeva 19, 36000 Kraljevo*
[1] *rasinac.m@mfkv.kg.ac.rs*
***TURBO SERVIS, Miloša Obrenovića bb, 31000 Užice, Serbia*

GEOMETRY AND MASS ANALYSIS OF WELDED SPOT

In resistance spot welding, microstructure of welded spot in middle cross section, normal to the welded sheets, is characterized with deformed elipse. Welded spot has a form of a lens with a two axis of symmetry, large one (diameter of welded spot - d_j) which coincides with the contact line of welded sheets, and small one (height of welded spot - h_j) which coincides with the axis of electrodes and is normal to the sheets, Figure 5. [1]

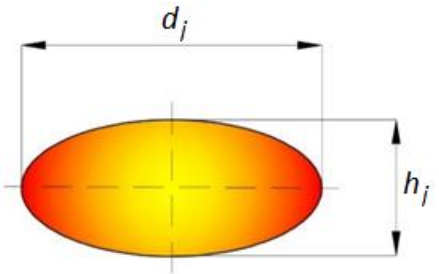

Figure 5. Shape of welded spot (liquid core). [1]

During the process of welding, diameter of liquid core d_j, after sudden increase at beginning later grows slowly asymptotically approaching to final value i.e., diameter of the welded spot which is defined with a diameter of contact surface of the electrode. So, it is ussual that $d_e = d$. Key role has a thickness of welded sheets. For purpose of determaining of d_j, in dependence of thickness of sheets, can be used tabelar values. [1] Shorter axis h_j can't be determined precisely without experiments, so its value is taken to be half of the thickness of welded sheets. In case of lap joint where the thickness of sheets are same, h_j is equal to the thickness of one welded sheet $(h_j = \delta)$.

Mass of welded spot can be calculated using the following equation:

$$m_{IM} = \rho \cdot V \qquad (1)$$

where the

$$V = \frac{4}{3}\pi \cdot d_j^2 \cdot h_j \qquad (2)$$

is volume of elipsoid (liquid core), that can be accepted with appoximate accuracy.

For each part of the car body we must calculate the mass of welded spot, because of different thickness of parts.

COST STRUCTURE OF RESISTANCE SPOT WELDING

Based on [1] and [3], total costs in resistance spot welding consists of:

*Faculty of Mechanical and Civil engineering, Dositejeva 19, 36000 Kraljevo
[1] rasinac.m@mfkv.kg.ac.rs
**TURBO SERVIS, Miloša Obrenovića bb, 31000 Užice, Serbia

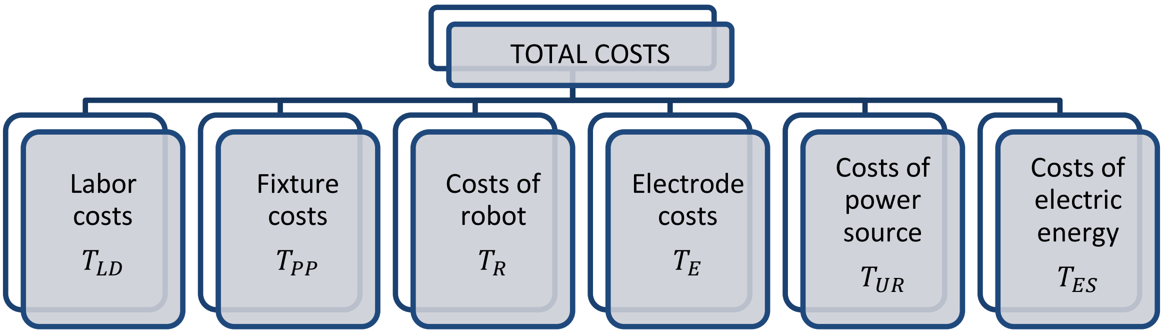

Figure 6. Total costs for resistance spot welding. [1]

Equations for costs are as follows.

Labor costs

$$T_{LD} = B_{LD} \cdot \frac{1}{\varepsilon \cdot K_{RR}} \cdot t_z, \text{[RSD/spot]} \qquad (3)$$

where the

$$K_{RR} = f \cdot 3600, \text{[s]}$$

Fixture costs

$$T_{PP} = t_z \cdot \frac{C_{KP} \cdot (1 + AM)}{\varepsilon \cdot K_R}, \text{[RSD/spot]} \qquad (4)$$

where the

$$K_R = e \cdot f \cdot 3600, \text{[s]}$$

Costs of robot

$$T_{RO} = \frac{T_{RO1}}{n_{T1}}, \text{[RSD]} \qquad (5)$$

where the

$$T_{RO1} = C_{RO} \cdot \frac{AM_{RO} + PD_{DZ}}{n_{gU}}, \text{[RSD/h]}$$

Electrode costs

$$T_E = 1.2 \cdot \frac{2C_E}{n_T}, \text{[RSD/spot]} \qquad (6)$$

Costs of power source

$$T_{UR} = \frac{T_{UR1}}{n_{T1}}, \text{[RSD/spot]} \qquad (7)$$

where the

**Faculty of Mechanical and Civil engineering, Dositejeva 19, 36000 Kraljevo*
[1] *rasinac.m@mfkv.kg.ac.rs*
***TURBO SERVIS, Miloša Obrenovića bb, 31000 Užice, Serbia*

$$T_{UR1} = C_{UR} \cdot \frac{AM_{UR} + PD_{DZ}}{n_{gU}}, [\text{RSD/h}]$$

Costs of electric energy

$$T_{ES} = C_S \cdot P \cdot t_z, [\text{RSD/spot}] \qquad (8)$$

where the

$$P = \frac{U \cdot I_z}{1000 \cdot \eta_s} \cdot \varepsilon + P_0 \cdot (1 - \varepsilon), [\text{kW/spot}]$$

And finally, total cost of welding one spot with resistance spot welding is obtained as a sum of all stated partial costs, as follows:

$$T_U = T_{LD} + T_{PP} + T_{RO} + T_E + T_{UR} + T_{ES}, [\text{RSD/spot}] \qquad (9) \quad [1]$$

CALCULATION OF WELDING COSTS WHEN PRODUCING A CAR BODY

If we assume that we have to calculate welding costs of some real car body, we have to consider the following parameters from production:

- ***welding current,***
- ***welding voltage,***
- ***thickness of sheets,***
- ***material of sheets,***
- ***diameter of the contact surface of the electrode,***
- **number of spots at the car body.** [1]

On the following figure we can see position of spots on certain parts of the car body.

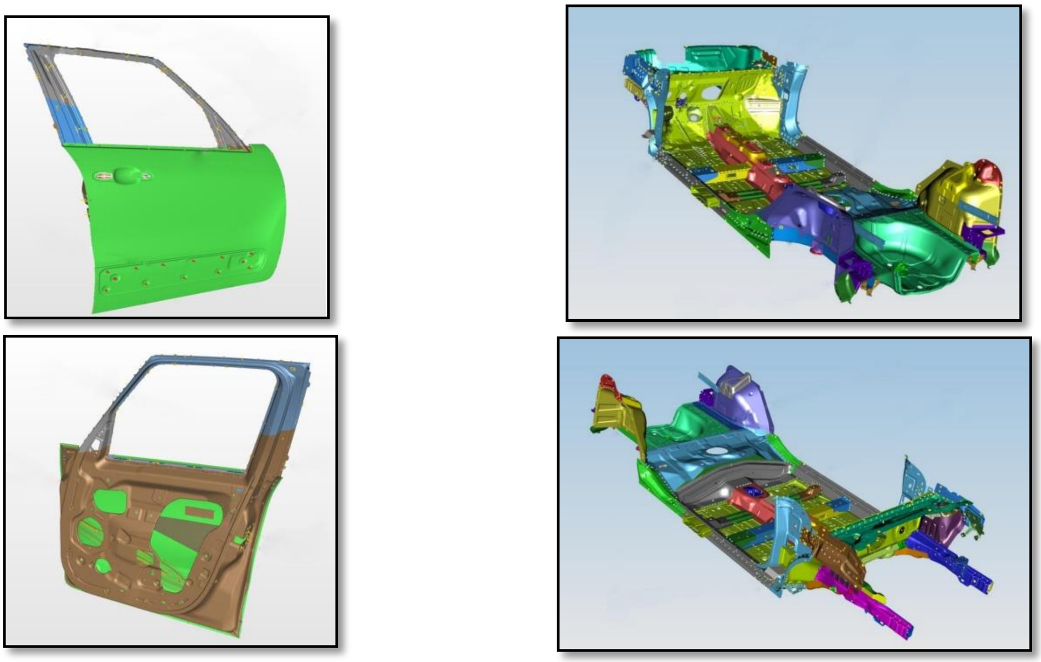

Figure 7. Some parts of the car body. [1]

**Faculty of Mechanical and Civil engineering, Dositejeva 19, 36000 Kraljevo*
[1] *rasinac.m@mfkv.kg.ac.rs*
***TURBO SERVIS, Miloša Obrenovića bb, 31000 Užice, Serbia*

In the next table are given the welding parameters needed for calculation of costs for each part of the car body.

Table 1. Welding parameters for each part of the car body.

Parts of car body	Welding current [A]	Welding voltage [V]	Thickness of sheet [mm]	Welding time of one spot [s]	Sheet material	Number of spots
Floor	8800	5.5	1.5	0.75	HCT690T	2418
Side panels	8300	4.6	1	0.5	HCT690T	2052
Roof	7600	4.2	0.8	0.4	HCT690T	382
Four doors	8800	5.5	1	0.5	HCT690T	3004
Doors of the trunk	8800	5.5	1	0.5	HCT690T	751
Hood	7600	4.2	0.8	0.4	HCT690T	195
Side wings	7600	4.2	0.8	0.4	HCT690T	780

On the next chart we can see amount of welding costs for all parts of the car body for total number of welded spots.

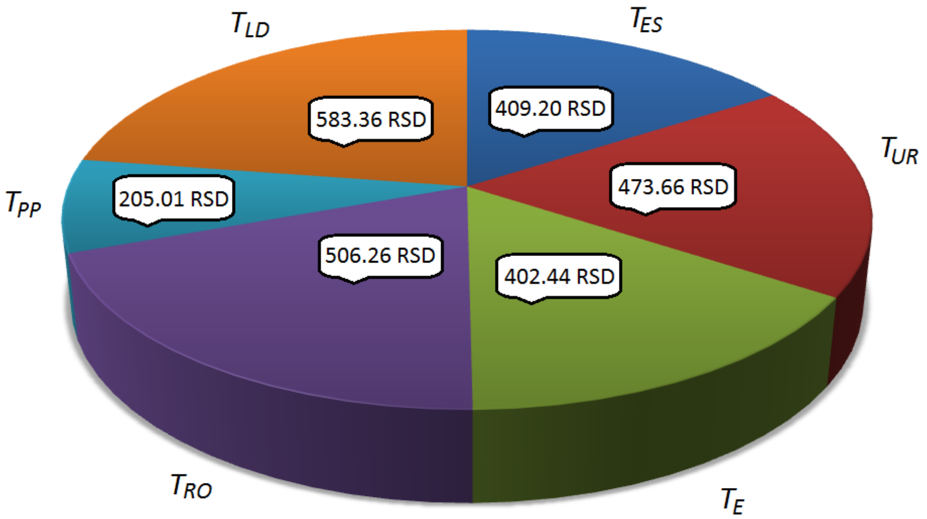

Figure 8. Amount of welding costs for all parts of the car body. [1]

**Faculty of Mechanical and Civil engineering, Dositejeva 19, 36000 Kraljevo*
[1] *rasinac.m@mfkv.kg.ac.rs*
***TURBO SERVIS, Miloša Obrenovića bb, 31000 Užice, Serbia*

CALCULATION OF COSTS OF EXPULSION DURING THE WELDING

Costs of expulsion of base material is calculated as follows:

$$T_{IS} = m_{IS} \cdot C_{OM} + C_S \cdot P \cdot t_{IS}, \text{[RSD]} \qquad (10)$$

where the:

$$m_{IS} = p_{is} \cdot m_{IM}, \text{[kg/spot]} \qquad (11)$$

represents mass of expulsed base material, p_{is}, [%] percentage of expulsed material and:

$$t_{IS} = t_z \cdot \frac{m_{IS}}{m_{IM}}, \text{[h]} \qquad (12)$$

time of expulsion.

Based on equations above, we can conclude that two main elements that influence on cost of extrusion are mass of expulsed material and the energy that this material possesses. Mass of expulsed material is impossible to be determined precisely without experimental tests carried out in the specific production conditions, therefore will be assume that value is 2, 4, 6, 8 and 10% of mass of liquid core m_{IM}.

On the following chart are shown costs of expulsion for every part of the car body, for 2% of expulsed base material for total number of welded spots.

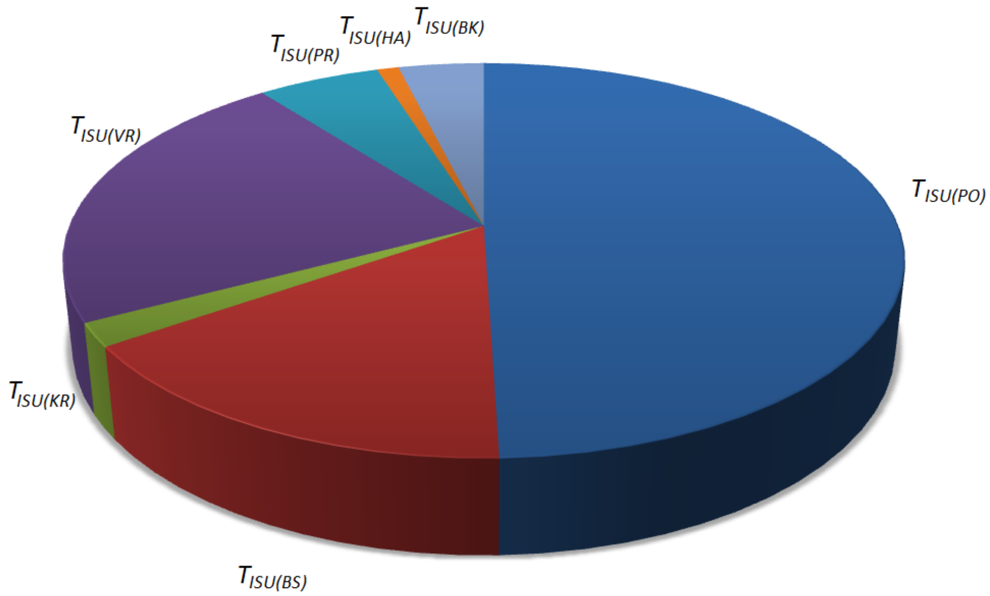

Figure 9. Costs of expuslion for parts of the car body. [1]

$T_{ISU(PO)} = 13.14$ [RSD], $T_{ISU(BS)} = 4.21$ [RSD], $T_{ISU(KR)} = 0.51$ [RSD], $T_{ISU(VR)} = 5.91$ [RSD], $T_{ISU(PR)} = 1.48$ [RSD], $T_{ISU(HA)} = 0.26$ [RSD], $T_{ISU(BK)} = 1.03$ [RSD].

Total cost of expulsion is:

$$T_{ISU} = T_{ISU(PO)} + T_{ISU(BS)} + T_{ISU(KR)} + T_{ISU(VR)} + T_{ISU(PR)} + T_{ISU(HA)} + T_{ISU(BK)}, \text{[RSD]}$$

$$T_{ISU} = 26.54 \text{ [RSD]}.$$

**Faculty of Mechanical and Civil engineering, Dositejeva 19, 36000 Kraljevo*
[1] *rasinac.m@mfkv.kg.ac.rs*
***TURBO SERVIS, Miloša Obrenovića bb, 31000 Užice, Serbia*

In the next table are given costs of expulsion for different values of percentage of expulsion.

Table 2. Costs of expulsion during year in [RSD], in dependence of percentage of expulsion. [1]

Parts of the car body	**Expulsion costs,** [RSD]				
	Percentage of expulsion, %				
	2	4	6	8	10
Floor	13.14	26.28	39.42	52.56	65.70
Side panels	4.21	8.42	12.63	16.84	21.05
Roof	0.51	1.02	1.53	2.04	2.55
Four doors	5.91	11.82	17.73	23.64	29.55
Doors of the trunk	1.48	2.96	4.44	5.92	7.40
Hood	0.26	0.52	0.78	1.04	1.30
Side wings	1.03	2.06	3.09	4.12	5.15
Costs of expulsion during welding one car body, [RSD]					
Total costs, [RSD]	26.54	53.08	79.62	106.16	132.70
Costs of expulsion of one year during welding 90 000 car bodies, [RSD]					
Total costs, [RSD]	2 388 600	4 777 200	7 165 800	9 554 400	11 943 000

The costs of expulsion are relatively low and varies from 0.26 [RSD] on hood to 65.7 [RSD] on floor for 2% of expulsed base material. But, in cost-effective sense, importance of this phenomenon is illustrated in increase of costs of expulsion in high series of car production, especially for the most pronounced material displacement of 10%. It is obvius that this type of costs should be included in the total costs of the process, Figure 6.

Therefore, can be concluded that phenomenon of expulsion is undesirable and it is sign of imperfection of of technology and it is necessary to take appropriate measures to avoid expulsion. [1],[2],[3]

**Faculty of Mechanical and Civil engineering, Dositejeva 19, 36000 Kraljevo*
[1] *rasinac.m@mfkv.kg.ac.rs*
***TURBO SERVIS, Miloša Obrenovića bb, 31000 Užice, Serbia*

CONCLUSIONS

In the production of welded structures, especially in automotive industry where are high series of car production, it is very important to properly select the welding parameters. In case that the parameters are choosen badly that causes additional costs which increase total welding costs and reduce the quality of welded joint. In this paper are shown costs that exists in resistance spot welding and their amount for production of car body for some supposed welding parameters. In addition to that there are analysed costs of expulsion for different values of percentage of expulsed base material. On the given charts we can see how phenomenon of expulsion affects on increase of total costs. On the Figure 10. are given participation of costs of expulsion of 2% in total costs. Based on conclusions made above, expulsion costs should be included in total costs of the process, especially in large series production of car body.

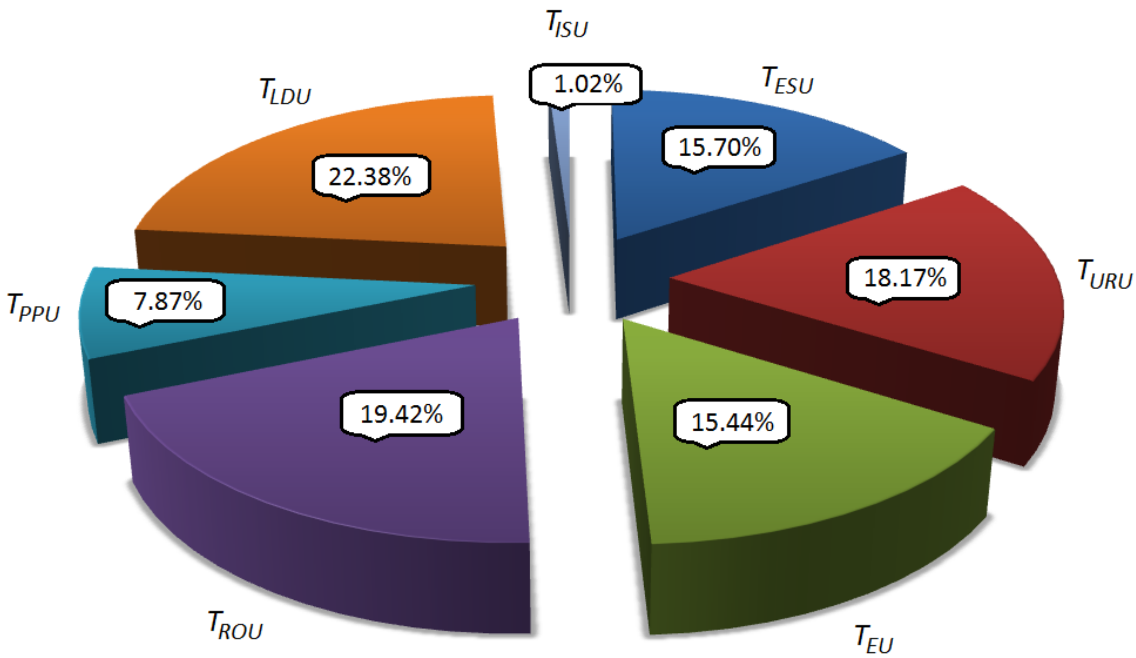

Figure 10. Chart of participation of expulsion phenomenon of 2% in total welding costs of car body. [1]

**Faculty of Mechanical and Civil engineering, Dositejeva 19, 36000 Kraljevo*
[1] *rasinac.m@mfkv.kg.ac.rs*
***TURBO SERVIS, Miloša Obrenovića bb, 31000 Užice, Serbia*

REFERENCES

/1/ Tešević, M., (2017) Determination of costs at occurence of expulsion at spot welding process, M. Sc. Thesis, University of Kragujevac, Faculty of Mechanical and Civil engineering in Kraljevo
/2/ Vukićević, M., (2013) Process design in welding technology – Book 1 – Weldability of materials, University of Kragujevac, Faculty of Mechanical and Civil engineering in Kraljevo
/3/ Vukićević, M., (2013) Process design in welding technology – Book 2 – Methodology, University of Kragujevac, Faculty of Mechanical and Civil engineering in Kraljevo
/4/ Zhang Z. D., Wang Y. R., Li D. Q., (2007) Expulsion in Resistance Spot Welding of AZ31B Magnesium Alloy, Materials Science Forum, Vols. 546-549, pp 443-446
/5/ Rajalakshmi, A., S., Shafiq, T., (2017) Modeling of Spot Weld with Failure for Crash Simulations,M. Sc. Thesis, Chalmers University of Technology, Department of Applied Mechanics Gothenburg, Sweden

**Faculty of Mechanical and Civil engineering, Dositejeva 19, 36000 Kraljevo*
[1] *rasinac.m@mfkv.kg.ac.rs*
***TURBO SERVIS, Miloša Obrenovića bb, 31000 Užice, Serbia*

NOMENCLATURE

$\boldsymbol{F}$, N – force of the electrode,

P – power switch,

$\mathbf{d_e}$, mm – diameter of contact surface of the electrode and sheet material,

δ, mm – thickness of sheet material,

d, mm – diameter of the welded point,

$\mathbf{H}, \mathbf{h_j}$, mm – height of the molten core,

$\mathbf{d_j}$, mm – diameter of the molten core,

$\boldsymbol{t}$, s – time,

$\boldsymbol{t_z}$, s – welding time,

$\boldsymbol{R_s}$, μΩ – total electrical resistance of the welded joint,

$\boldsymbol{R_{min}}$, μΩ – minimum electrical resistance,

$\boldsymbol{R_{max}}$, μΩ – maximum electrical resistance,

$\boldsymbol{R_{dk}}$, μΩ – electrical resistance of contact surface of the sheet,

$\boldsymbol{R_c}$, μΩ – contact resistance of joint,

α – point of minimum electrical resistance,

β – point of maximum electrical resistance,

ν – point of material displacement,

$\boldsymbol{m_{IM}}$, kg – mass of welded spot (liquid core),

$\boldsymbol{\rho}$, kg/m^3 – density of sheet material,

$\boldsymbol{V}$, m^3 – volume of welded spot (liquid core),

$\boldsymbol{T_{LD}}, \boldsymbol{T_{LDU}}$, RSD – labor costs and total labor costs,

$\boldsymbol{T_{PP}}, \boldsymbol{T_{PPU}}$, RSD – fixture costs and total fixture costs,

$\boldsymbol{T_R}, \boldsymbol{T_{RU}}$, RSD – costs of robot and total costs of robot,

$\boldsymbol{T_E}, \boldsymbol{T_{EU}}$, RSD – costs of electrode and total costs of electrode,

$\boldsymbol{T_{UR}}, \boldsymbol{T_{URU}}$, RSD – costs of power source and total costs of power source,

$\boldsymbol{T_{ES}}, \boldsymbol{T_{ESU}}$, RSD – costs of electric energy and total costs of electric energy,

$\boldsymbol{B_{LD}}$, RSD – gross amount of employees' personal income,

$\boldsymbol{\varepsilon}$ – intermittence,

$\boldsymbol{K_{RR}}$, s – work time of the employee in one month,

$\boldsymbol{f}$ – number of hours of work in one month,

$\boldsymbol{C_{KP}}$, RSD – the cost of auxiliary accessories,

$\boldsymbol{AM}$ – annual depreciation rate of auxiliary accessories,

$\boldsymbol{K_R}$, s – the time of using accessories in one year,

$\boldsymbol{e}$ – number of months of work in one year,

$\boldsymbol{T_{RO}}$, RSD – total costs of welding robot,

$\boldsymbol{T_{RO1}}$, RSD/h – cost of welding robot per one hour of work,

$\boldsymbol{n_{T1}}$, spot/h – number of spots welded for one hour,

$\boldsymbol{C_{RO}}$, RSD – the cost of robot,

$\boldsymbol{AM_{RO}}$ – annual depreciation rate of robot,

*Faculty of Mechanical and Civil engineering, Dositejeva 19, 36000 Kraljevo
[1] rasinac.m@mfkv.kg.ac.rs
**TURBO SERVIS, Miloša Obrenovića bb, 31000 Užice, Serbia

$\boldsymbol{PD_{DZ}}$ – taxes and contributions prescribed by the community,

$\boldsymbol{n_{gU}}$, h – annual number of hours of work of robot,

$\boldsymbol{C_E}$, RSD – the cost of electrode,

$\boldsymbol{n_T}$ – number of welded spots,

$\boldsymbol{T_{UR1}}$, RSD/h – costs of power source per one hour of work,

$\boldsymbol{n_{T1}}$, spot/h – number of welded spots in one hour,

$\boldsymbol{C_{UR}}$, RSD – the cost of power source,

$\boldsymbol{AM_{UR}}$ – annual depreciation rate of power source,

$\boldsymbol{C_S}$, RSD/kWh – cost of electric energy,

$\boldsymbol{P}$, kW/spot – engaged power for welding of power source,

$\boldsymbol{U}$, V – welding voltage,

$\boldsymbol{I_z}$, A – welding current,

$\boldsymbol{\eta_S}$ – degree of exploitation,

$\boldsymbol{P_o}$, kW – idle power of power source,

$\boldsymbol{T_U}$, RSD/spot – total costs of welding one spot,

$\boldsymbol{T_{IS}}$, RSD – costs of expulsion,

$\boldsymbol{m_{IS}}$, kg/spot – mass of expulsed base material,

$\boldsymbol{C_{OM}}$, RSD/kg – cost of base material,

$\boldsymbol{t_{IS}}$, s – time of expulsion,

$\boldsymbol{p_{is}}$, % – percentage of expulsed base material,

$\boldsymbol{T_{ISU(PO)}}$, RSD – total costs of expulsion for welding floor,

$\boldsymbol{T_{ISU(BS)}}$, RSD – total costs of expulsion for welding side panels,

$\boldsymbol{T_{ISU(KR)}}$, RSD – total costs of expulsion for welding roof,

$\boldsymbol{T_{ISU(VR)}}$, RSD – total costs of expulsion for welding four doors,

$\boldsymbol{T_{ISU(PR)}}$, RSD – total costs of expulsion for welding doors of the trunk,

$\boldsymbol{T_{ISU(HA)}}$, RSD – total costs of expulsion for welding hood,

$\boldsymbol{T_{ISU(BK)}}$, RSD – total costs of expulsion for welding side wings,

$\boldsymbol{T_{ISU}}$, RSD – total costs of expulsion for welding car body

**Faculty of Mechanical and Civil engineering, Dositejeva 19, 36000 Kraljevo*
[1] *rasinac.m@mfkv.kg.ac.rs*
***TURBO SERVIS, Miloša Obrenovića bb, 31000 Užice, Serbia*