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## INFLUENCE OF WELDING PARAMETERS ON MECHANICAL PROPERTIES OF WELDED JOINT AT CAPACITY DISCHARGE WELDING PROCESS

## UTICAJ PARAMETARA ZAVRIVANJA NA MEHANIČKE OSOBINE ZAVARENIH SPOJEVA KOD PERKUSIONOG KONDENZATORSKOG ZAVARIVANJA

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### Abstract

Capacity discharge percussion welding is nonconventional welding process where heat source is an electric arc obtained by discharging of capacitor bank. The arching time is very short, around 10 ms, and depends on a few parameters such as: capacity of capacitor bank, voltage, movement speed of welded pieces during welding. During arching a certain amount of material is melted and after that squeezed out by applied force used in welding process. Quantity of squeezed material depends upon heat input, intensity of the force pressing the wires during welding and many other parameters. Mechanical properties of welded joints depend on welding parameters. In this paper is described the influence of capacity discharge percussion welding parameters on mechanical properties of welded joints.

### Rezime

Perkusiono kondenzatorsko zavarivanje je nekonvencionalni postupak zavarivanja koji kao izvor toplote koristi električni luk dobijen pražnjenjem kondenzatorske baterije. Vrijeme gorenja električnog luka je dosta kratko, reda oko 10 ms i zavisi od više parametara, u prvom redu kapaciteta kondenzatorske banke, napona do kojeg su napunjeni kondenzatori, brzine primicanja komada koji se međusobno zavaruju. Za vrijeme procesa gorenja električnog luka se topi određena količina metala koja nakon toga biva istisnuta pod dejstvom sile kojom se pritiskuju žice u toku zavarivanja. Količina istisnutog metala zavisi od unosa toplote, intenziteta pritiskivanja žica u toku zavarivanja, kao i drugih parametara. Mehaničke osobine također zavise od parametara zavarivanja. U ovom radu je opisan uticaj parametara zavarivanja na mehaničke osobine zavarenih spojeva kod kondenzatorskog perkusionog zavarivanja.

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## 1. Introduction

All welding processes that use capacitor capacity as an energy source are considered capacitor discharge welding processes. There are a number of these processes, however, the most common are capacitor discharge percussion welding - CDPW, CD stud welding and capacitor discharge welding. [1]

Capacitor discharge percussion welding is a butt welding method of the metal pieces under the influence of a mechanical load applied during or immediately after an electric arc burning. The arc is obtained by discharging the energy previously stored to the capacitors in order to melt the connecting surfaces. [2]

A main characteristic of a capacitor discharge percussion welding compared to other capacitor discharge welding processes is a creation of the joints in solid phase during mutual moving of the pieces to be joined. This moving causes collisions of work pieces at the end of the process and provides a relatively constant electric arc. [1, 2]

There are several parameters on which welding process depends, but as main influencing parameters are determined:

- charging voltage of capacitors bank,
- capacity of capacitors bank,
- intensity of a pressing force of the wires during welding,
- velocity of the wires during welding.

Thus, by discharging the capacitor bank, a short term electric arc is generated and melts a certain amount of metal. After that, the pieces are mutually joined with certain force. This is the main reason why this process is commonly used for joining wires and similar shape products of small dimensions. In this paper were used the wires made of austenitic steel and the influence on welding parameters related to a mechanical properties of a welded joint was analysed.

## 2. Experimental procedure

In the experimental part of this paper the main goal was to show the influence of welding parameters on mechanical properties of the welded joint. The idea was to choose the optimal parameters in order to get the welded joints with the best mechanical properties as well as the best geometry. All the above mentioned was planned to be achieved by varying a heat input, a force pressuring a pieces during welding and electric arc burning time. A heat input was varied in two ways. First way was to change voltage of capacitor bank and the other was to change capacity of capacitor bank. Varying of the time of burning of the electric arc was being done by changing the velocity of the approaching of the wires during welding, among other parameters. The velocity was being changed by changing duration of the step on stepper motor which was used for approaching of the wires during welding. The experiment was executed with two different diameters of wires, 1,0 mm and 1,6 mm.

The samples used for welding were made of austenitic steel CrNi19-9, which chemical composition is given in the table 1.

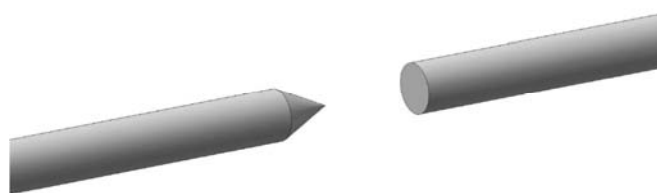
**Table 1.** Chemical composition of parent material

**Tabela 1.** Hemijski sastav osnovnog materijala

Material grade acc. DIN	C <sub>max</sub> [%]	Si [%]	Mn [%]	Cr [%]	Ni [%]	Fe [%]
<b>ER 308LSi</b>	0,03	0,88	1,0-2,5	19,0-22,0	9,0-11,0	rest

In order to get a repeatability of the results, all the samples were prepared in same way. A front surface of one wire was flat, and the same surface

of another wire was conically processed under the angle of approximately 60 degrees, figure 1.



**Figure 1.** Welded joint preparation [4]

**Slika 1.** Priprema zavarenog spoja [4]



This way of preparing samples geometry is chosen because of very small diameters, which means that the standard preparations, given by ISO, would be very difficult to execute. Before the main experiment, a preliminary one was executed with a goal to determine the boundaries of the parameters.

Knowing the nature of the welding process it was decided to vary the parameters on three levels inside the established boundaries. It was decided to base the experiment on Taguchi's robust method in order to minimize the number of the samples. Based on the number of parameters or factors and the number of levels on which parameters were planned to vary, using this method there were available L9 and L27 matrices. An L9 matrix was chosen for this experiment with four factors on three levels.

Through preliminary experiment for 1,0 mm diameter wire it was determined that the values of the parameters should be inside the boundaries given in table 2. All other parameters were taken as unchangeable, the polarity was taken in a way that the flat wire was connected to a positive pole, total displacement of the jaws was limited to 10 iterations of stepper motor, the welding was executed in argon protection atmosphere. With these parameters filled in an orthogonal matrix, the design of the experiment is generated as shown in table 2.

**Table 2.** Design of experiment for 1,0 mm wire [4]

**Tabela 2.** Parametri procesa za eksperimente za žicu od 1,0 mm [4]

Exp. No.	Voltage [V]	Capacity [mF]	Force [N]	Speed [mm/s]
M1	45	8,8	4,7	16,3
M2	45	13,2	5,7	13,1
M3	45	17,6	6,7	9,8
M4	60	8,8	5,7	9,8
M5	60	13,2	6,7	16,3
M6	60	17,6	4,7	13,1
M7	90	8,8	6,7	13,1
M8	90	13,2	4,7	9,8
M9	90	17,6	5,7	16,3

Using the same principle, the procedure was implemented for 1,6 mm diameter wire. Because of higher diameter wire, higher heat input was

needed. Based on this, the design of the experiment was executed as given in table 3.

**Table 3.** Design of experiment for 1,6 mm wire [4]

**Tabela 3.** Parametri procesa za eksperimente za žicu od 1,6 mm [4]

Exp. No.	Voltage [V]	Capacity [mF]	Force [N]	Speed [mm/s]
V1	70	17,6	6,2	16,3
V2	70	22,0	6,7	13,1
V3	70	26,4	7,3	9,8
V4	80	17,6	6,7	9,8
V5	80	22,0	7,3	16,3
V6	80	26,4	6,2	7,3
V7	90	17,6	6,2	13,1
V8	90	22,0	6,7	9,8
V9	90	26,4	7,3	16,3

The experimental samples were being welded following the design of experiment with three repetitions. The heat input was being changed by changing the capacity, hence alternate switching of different number of capacitors as well as by changing the voltage of capacitor bank. The shape of a current impulse as well as the voltage during welding was recorded on computer so it was possible to follow the value of current and the welding process duration.

After the welding, the samples were photographed with a suitable magnification to evaluate the joint geometry. After that, the examination of tensile strength was executed. Considering specimens dimensions, and fact that expected failure is at HAZ, only reasonable parameter of mechanical properties for analysis was tensile strength. Tensile testing was done on hydraulic tensile testing machine HMT.50.EM, which has maximum force of 50 kN. Beside of tensile strength of material at one sample from each parameter set was measured hardness.

In tensile strength rating, as main parameter average tensile strength was primary parameter, and as STDEV was rated as second criteria. Reason for this doubled rating is because of consideration that samples with huge amount of squeezed melted material will have higher tensile strength. Results of tensile testing are given at table 3. for 1,0 mm wires diameter and table 4. for 1,6 mm wire diameter.

**Table 4** Experiment results of 1,0 mm wire [4]**Tabela 4.** Rezultati eksperimenta sa žicom od 1,0 mm [4]

Parameter set	Tensile strength [MPa]				
	Specimen			Average	STDEV
	1	2	3		
M1	793,2	743,5	721,9	752,9	50,8
M2	910,3	842,8	817,4	856,9	66,8
M3	786,8	611,1	663,3	687,1	125,4
M4	623,8	693,9	713,0	676,9	65,2
M5	761,4	827,6	567,8	718,9	187,7
M6	942,2	552,3	928,0	807,5	307,5
M7	873,1	819,9	783,0	825,4	63,0
M8	766,8	804,6	962,4	844,6	144,2
M9	891,2	929,2	896,3	905,6	28,6

**Table 5.** Experiment results of 1,6 mm wire [4]**Tabela 5.** Rezultati eksperimenta sa žicom od 1,6 mm [4]

Parameter set	Tensile strength [MPa]				
	Specimen			Average	STDEV
	1	2	3		
V1	655,5	678,9	306,9	547,1	416,6
V2	596,8	596,8	711,2	634,9	132,0
V3	661,4	603,7	714,2	659,8	110,4
V4	675,4	648,0	504,8	609,4	183,2
V5	0,00	0,0	0,0	0	0
V6	531,5	707,2	690,3	643,0	193,8
V7	686,3	709,7	742,5	712,8	56,4
V8	628,1	603,7	674,9	635,6	72,2
V9	763,9	721,1	596,8	693,9	173,6

Form those data can be seen that samples with M9 set of welding parameters have the best average tensile strength and smallest STDEV at

the same time for 1,0 mm wire diameter. For 1,6 mm wire diameter the best average tensile strength and smallest STDEV value is at V7 set of welding parameters. As the input parameter for Taguchi's analysis is taken a mean value for each set of experimental samples. Taguchi's analysis showed that the voltage is the most influential factor in both the mean values, the signal-to-noise ratio, as well as in standard deviations, table 6.

**Table 6.** Response table for 1,0 mm wire [4]**Tabela 6.** Tabela odgovora za žicu od 1,0 mm [4]

Response Table for Signal to Noise Ratios Larger is better					
Level	Voltage	Capacity	Force	Speed	
1	52,45	51,21	51,78	52,17	
2	53,53	52,77	52,19	53,10	
3	50,49	52,48	52,49	51,19	
Delta	3,04	1,57	0,72	1,91	
Rank	1	3	4	2	

Response Table for Means					
Level	Voltage	Capacity	Force	Speed	
1	429,4	365,3	412,2	430,7	
2	507,3	469,5	417,2	474,7	
3	337,5	439,4	444,7	368,8	
Delta	169,8	104,1	32,5	105,8	
Rank	1	3	4	2	

Response Table for Standard Deviations					
Level	Voltage	Capacity	Force	Speed	
1	49,64	23,20	70,77	72,45	
2	110,88	98,56	43,89	76,25	
3	25,43	64,18	71,28	37,25	
Delta	85,46	75,36	27,38	39,00	
Rank	1	2	4	3	

The second most influential factor in the mean values and the signal-to-noise ratio is the speed of the wire approaching during welding, i.e. the duration of arc burning. By standard deviation, this parameter is only in third place. After that, the capacity of the capacitor bank is the third most influential factor, while at standard deviations the capacity of the capacitor bank is the second most



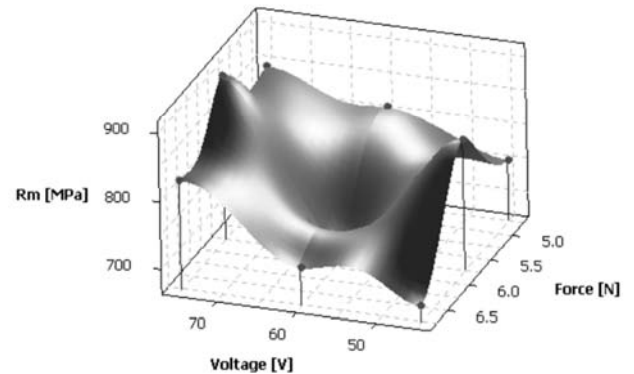
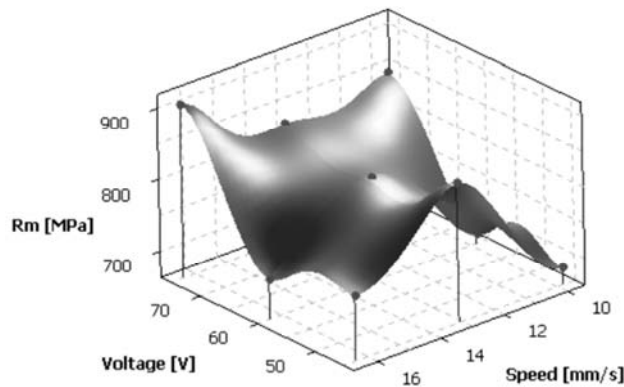
influential factor. And finally, all analyzes showed that force is on the last place.

**3. Results and discussion**

The influence of several welding parameters on the average value of tensile strength was analyzed, and since it is a very complex process, the dependence on combinations of certain parameters is shown. In Taguchi's analysis, voltage proved to be the most influential factor. Since, in the

expression for the energy on the capacitor, the voltage has a square potency, unlike other parameters, the voltage, with a small error, can be considered as the heat input.

As shown in Figure 5, the average value of the tensile strength of the welded joint increases with increasing voltage, i.e. heat input. At the same time, the influence of the wire approach speed, as well as the force intensity, cannot be clearly related.

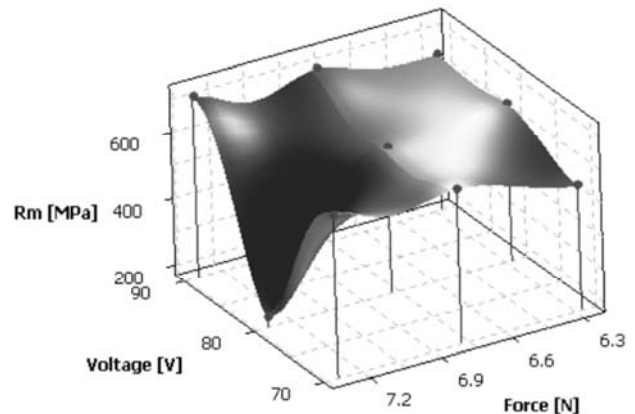
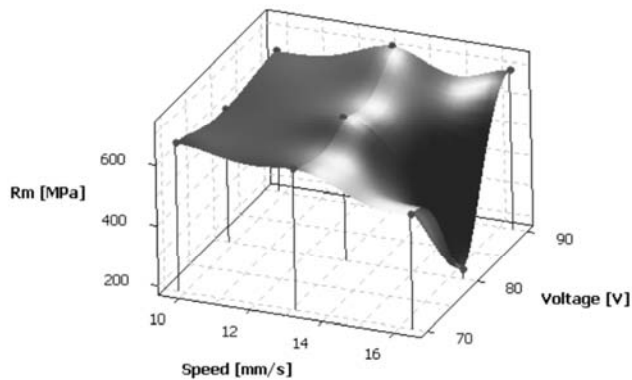


**Figure 5.** Dependence of tensile strength on welding parameters for 1,0 mm wire [4]

**Slika 5.** Zavisnost zatezne čvrstoće od parametara zavarivanja žice od 1,0 mm [4]

In general, the best result is for the medium wire approach speed, except for the maximum voltage. Impact of force pressing wires in combination with

voltage is quite complex analyzed. The best results were achieved in combination of extreme values of those parameters.

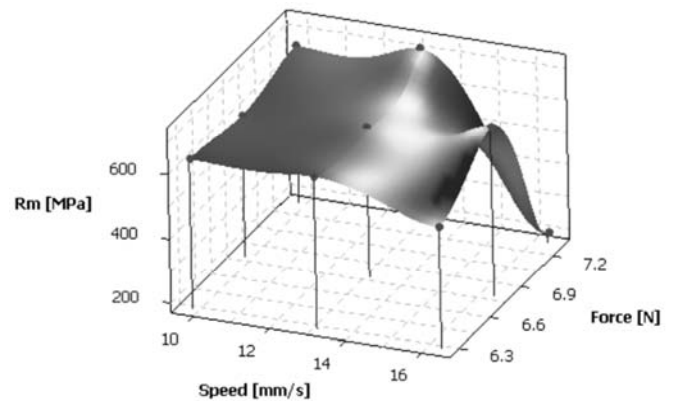
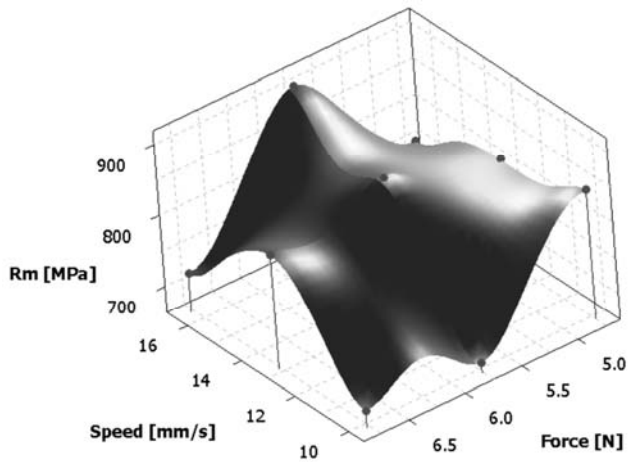


**Figure 6.** Dependence of tensile strength on welding parameters for 1,6 mm wire [4]

**Slika 6.** Zavisnost zatezne čvrstoće od parametara zavarivanja žice od 1,6 mm [4]

At 1,6 mm diameter wires can be concluded that increasing heat results with higher tensile strength. At the same time, in combination with other parameters, increasing approaching speed of wires results with better tensile strength values, as well as increasing force pressing wires during welding. In both cases maximum values of these parameters in combination with mean value of voltage have the worst result.

Analysing the dependence of tensile strength from the combination of force and velocity, at both wire diameters, it can be observed that the best results are in the combination of the mean values of these parameters. By analysing the extremes, it can be concluded that combinations of higher force and lower speed and vice versa give a better result.

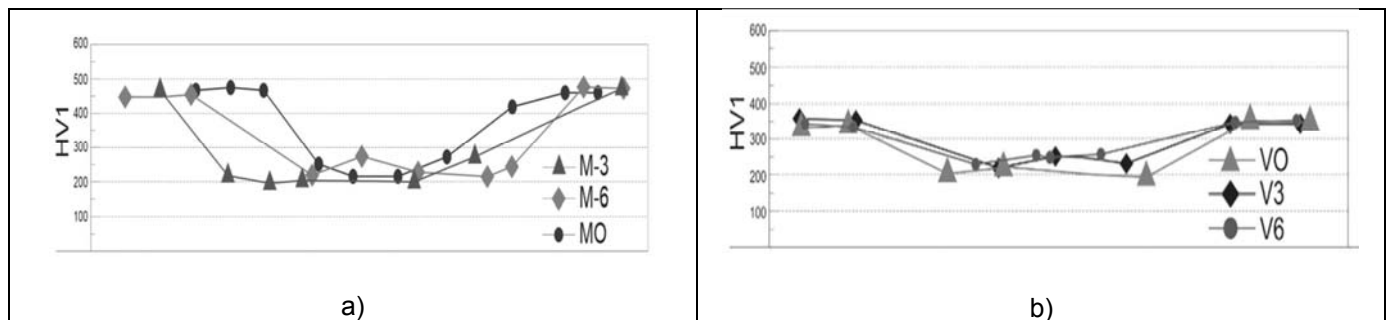


**Figure 7.** Dependence of tensile strength on welding parameters for 1,0 mm and 1,6 mm wires [4]

**Slika 7.** Zavisnost zatezne čvrstoće od parametara zavarivanja za žice od 1,0 mm i 1,6 mm [4]

Based on Taguchi analyses for both wire diameters optimal parameters were determined, and samples were welded using those parameters. Those samples justified expectations. Beside of the

tensile strength, on three parameter sets samples hardness HV1 was measured. Measured values are shown on figure 8.



**Figure 8.** Dependence of hardness on welding parameters for 1,0 mm and 1,6 mm wires [4]

**Slika 8.** Zavisnost tvrdoće od parametara zavarivanja za žice od 1,0 mm i 1,6 mm [4]

#### 4. Conclusion

Based on the conducted experimental research and statistical processing of the results, the following can be concluded:

The voltage of charging the capacitor bank is the most effective parameter of the welding process on tensile strength of welded joints. Reason for that is in fact that voltage exponentially affects the heat input. From the charging voltage of the capacitor bank depends the intensity of the current during welding, which reflects on the amount of melted material. With the increase of the voltage, the amount of melted metal increases, which in combination with other parameters has a direct impact on the geometry of the welded joint, the mechanical characteristics and hardness of the joint, as well as the metallography.

#### 4. Zaključak

Na osnovu sprovedenog eksperimentalnog istraživanja i statističke obrade rezultata može se zaključiti sledeće:

Napon punjenja kondenzatorske baterije je najefikasniji parametar procesa zavarivanja za zateznu čvrstoću zavarenih spojeva. Razlog za to je činjenica što napon eksponencijalno utiče na unos toplote. Od napona punjenja kondenzatorske baterije zavisi intenzitet struje tokom zavarivanja, što se odražava na količinu rastopljenog materijala. Sa povećanjem napona povećava se količina istopljenog metala, što u kombinaciji sa drugim parametrima ima direktan uticaj na geometriju zavarenog spoja, mehaničke karakteristike i tvrdoću spoja, kao i na metalografiju.



The second most influential parameter is the speed of approaching of the wires during welding, from which depends the total duration of the welding process (arcing time). It was noted that the speed of approaching of the wires during welding affects the intensity of the current at the first pulse in such a way that with the increase in the speed of approach of the wires the intensity of the current rises slightly to a certain value, and then again decreases. The influence of the welding speed on the amount of squeezed metal weld is not unambiguous and there are significant differences in the effect at different wire diameters.

The pressure force intensity of the wires during welding in some cases is in the second, and in some in the third place, as a factor that impacts the welding process. In general, the influence of the pressure force intensity of the wires during welding on the characteristics of the welded joint is not unambiguous. Therefore, it is observed in combination with other parameters of the welding process.

The analysis showed that the smallest influence on the welding process has the capacity of the capacitor bank, and it is not possible to notice a certain dependence of the characteristics of the joint from the capacity of the capacitor bank.

Analysing hardness shows reduction of hardness at welding zone. It was expected because parent material is in cold drawn state. This reduction of hardness is more significant at 1,0 mm diameter wires that is because those wires have higher hardness in general. All samples show smaller hardness at HAZ than in welded metal. Samples welded with higher heat input have more pronounced hardness decrement, and those wires were connected on anode during welding. It can be concluded that hardness has expected dependence on heat input as well as polarity of wires.

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Drugi najuticajniji parametar je brzina približavanja žica tokom zavarivanja, od čega zavisi ukupno trajanje procesa zavarivanja (vreme pražnjenja luka). Primećeno je da brzina približavanja žica tokom zavarivanja utiče na intenzitet struje pri prvom impulsu na način da sa povećanjem brzine približavanja žica intenzitet struje blago raste do određene vrednosti, a zatim ponovo opada. Uticaj brzine zavarivanja na količinu stisnutog metalnog šava nije jednoznačan i postoje značajne razlike u efektu kod različitih prečnika žice

Intenzitet sile pritiska žica pri zavarivanju u nekim slučajevima je na drugom, a u nekim na trećem mestu, kao faktor koji utiče na proces zavarivanja. Generalno, uticaj intenziteta sile pritiska žica tokom zavarivanja na karakteristike zavarenog spoja nije jednoznačan. Stoga se posmatra u kombinaciji sa drugim parametrima procesa zavarivanja.

Analiza je pokazala da najmanji uticaj na proces zavarivanja ima kapacitet baterije kondenzatora, te se ne može uočiti određena zavisnost karakteristika spoja od kapaciteta kondenzatorske baterije.

Analiza tvrdoće pokazuje smanjenje tvrdoće u zoni zavarivanja. Očekivano je jer je osnovni materijal u hladno vučenom stanju. Ovo smanjenje tvrdoće je značajnije kod žica prečnika 1,0 mm, jer te žice uopšte imaju veću tvrdoću. Svi uzorci pokazuju manju tvrdoću na HAZ nego u zavarenom metalu. Uzorci zavareni sa većim unosom toplote imaju izraženiji opadanje tvrdoće, a te žice su pri zavarivanju bile povezane na anodu. Može se zaključiti da tvrdoća ima očekivanu zavisnost od unešene toplote kao i polariteta žica.

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