Experimental study of the contact resistance of crossed cylindrical reinforcing steel bars

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In the paper experimental results for the contact resistance between two cross-pressed cylindrical bars of reinforcing steel bars are presented. The diameters of the investigated samples were from 6 to 10mm. At a DC measurement current up to 50A and a pressure force on the investigated samples up to 500N, average values of the contact resistance in the range of 0,3 to 5 mΩ have been fixed and reported. The influence of the surface conditions is also discussed and corresponding data are presented.

Експериментално изследване на контактно съпротивление на кръстосано притиснати телове от арматурна стомана. (Деница Държанова, Марина Манилова, Костадин Миланов). *В статията са представени резултати от експериментално изследване на контактното съпротивление между два кръстосано притиснати цилиндрични образци от арматурна стомана. Диаметърът на образците е от 6 до 10мм. При измервателен ток до 50А и сила на притискане на образците до 500N, са посочени средни стойности за измереното контактно съпротивление в обхвата от 0,3 to 5 mΩ. Дискутирано е и състоянието на повърхността на образците като са приведени съответни данни за нейното влияние върху контактното съпротивление.*

Introduction

Spot resistance welding of crossed reinforcing steel wires and bars is modern, effective and widely used technological process. The welding (Fig.1, Fig.2) takes place at rather low voltage of 5÷6 V, but the current values may reach 10÷15kA. The duration of the process usually is in the range of 100 to 500 ms. The quality of the welded joints to a considerable degree depends on the pressure maintained on the welded samples, together with the specified values for the welding current and its duration – i.e. the time-current combination (TCC) [2,3]. The amount of the melted metal volume depends on the energy dissipated in the contact area between the welded samples, which also makes the role of the contact resistance between those samples vital for the process.

Investigations of the contact resistance between two metal cylindrical samples have been provided for a long time, mainly for the design purposes in the field of electrical apparatuses (high and low current circuit breakers) [1]. It has been proved that from theoretical viewpoint the current flow in the contact area is identical for both cross positioned and pressed cylinders (Fig.2) and cross-section face to face positioned cylinders. Additional discussions for crossed cylinders, supported by some experimental data have been reported in [4], [5], but only for copper, aluminum and brass-materials used mainly in electrical engineering. The samples diameter was limited to only 6mm

Fig.1. The spot resistance welding machine.

In this paper attention has been focused on reinforcing steel cylindrical samples having diameters of 6, 8 and 10 mm. The results reported are entirely experimentally obtained and processed.

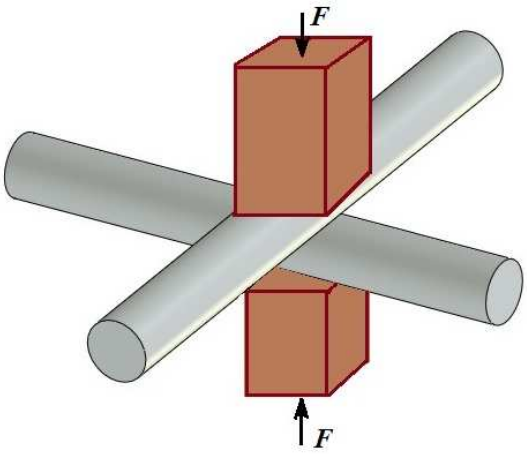

Fig.2. Illustration of spot resistance welding of crossed cylinders.

The experimental set and samples investigated.

In Fig.3 a view on the experimental set used is presented. The contact pressure has been realized by consecutively adding of 5 equal weights, each one having a mass of 2,04 kg. Due to arm 1 the actual pressure force F on the investigated samples 2 and 3 has been increased 5 times, so that the actual pressure on the samples was maintained from 100 to 500N.

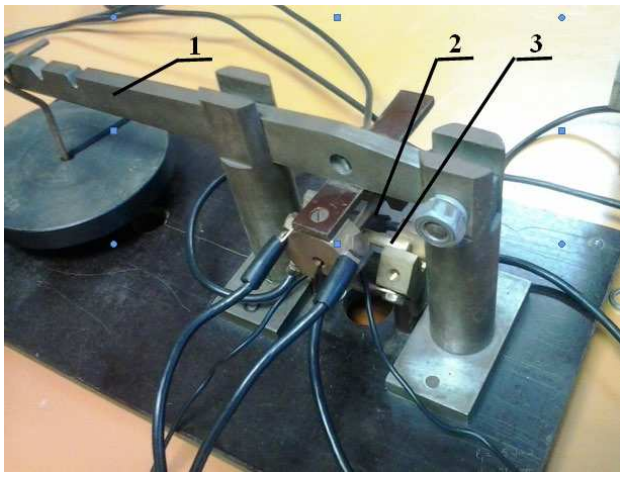

Fig.3. The mechanical part of the experimental set for the contact resistance measurement.

A view of the steel bars samples is presented on Fig.4, while in Fig.5 the electrical scheme used for the contact resistance R_k measurement is illustrated. The total measurement current I flowing trough the contact area of interest is considered practically equally divided between the two adjacent samples halfs. The voltage drop for convenience has been measured at the ends of the two samples. Correction was introduced for the preliminary value of the contact resistance $R_m = \dfrac{\Delta U}{I}$ (calculated from the measurement results) to get the sought value of R_k .

(1) $$R_k = R_m - \frac{R_0}{2},$$

where R_0 is the resistance between the two ends of a sample for ambient temperature value of 20^0C.

Thus for all the experimental results the systematic error from measurement point of view in great extent is considered eliminated. The calculated values of the resistance R_0 at a sample length of 60mm, taking the resistivity of that kind of steels [6] to be 15 μΩ.cm at 20^0C are presented in Table 1 for all the 3 diameters of the investigated steel samples.

Table 1

The sample'scalculated correction resistance

The sample diameter [mm]	6	8	10
Resistance R_0 [μΩ]	320	150	115

The total current value I has been controlled via auto-transformer ATp in the range 30÷50A, and measured via shunt 100A / 60 mV, while for the voltage drop ΔU measurement precise DC voltmeter was used.

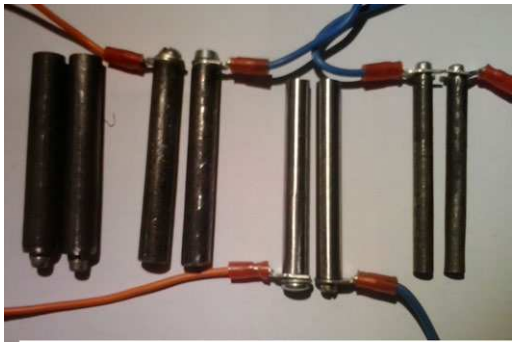

Fig.4. Experimental samples.

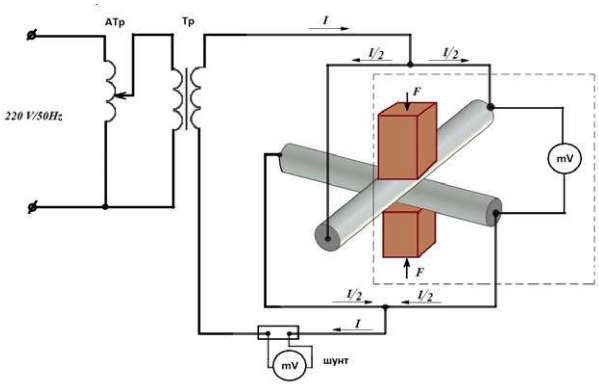

Fig.5. Electrical scheme used for the contact resistance measurement.

Experimental results

For the contact resistance R_k study two groups have been provided

- **Basic group** – Experiments were performed on all the 3 different diameters samples. The current I was kept constant, while the pressure force F was increased progressively from 100 to 500N. The samples surface was in two different states – first untouched (factory delivered) and second time **conditioned** (treated 1 min. in sulfur acid solution of density 1,28, then washed and dried).
- **Additional group** – Only samples having diameter of 8mm have been investigated. At one and the same measurement current I and two different pressure forces F, the influence of surface layers (films) conditioning (up to mechanically removing them) was subject of investigation.

Results obtained for the basic group of samples

Samples of diameter d=6 mm.

In Table 2 results for the average value of the contact resistance R_k $[m\Omega]$ based on 3 separate measurements are presented. The contact pressure force F was maintained for the whole accepted range between 100 and 500N. To get an idea for the dispersion of the measurement results around the presented average value, the standard deviation S is also presented, thus it becomes also possible to calculate the Student's coefficients [7] – respectively the probability of the expected value for the R_k $[m\Omega]$ in a certain confidential interval around the presented value in Table 2. For example at pressure force of 500N and measurement current of 30A, the confidential 90% probability interval of R_k takes the value of 0,5mΩ, i.e. $R_k = 3{,}57 \pm 0{,}5 \ m\Omega$. For the same confidential probability of 90%, but at measurement current of 50A the result is $R_k = 2{,}48 \pm 0{,}12 \ m\Omega$.

Diagrams illustrating the relationship of R_k $[m\Omega]$ versus the applied contact pressure force F at given constant measurement current I are presented in Fig.6 for the natural surface condition and in Fig.7 after conditioning of the samples surface. The difference with the results reported for copper in [4] is that for untreated surface of the samples the increase of the measurement current decreases the contact resistance value by 20÷30%, which is significant.

Same effect has been observed for conditioned surface of the samples but the difference is much smaller. As it was expected theoretically the increase of the pressure force F decreases the contact resistance. This effect is more essential after the sample's surface was conditioned and show that the contact resistance is expected to get much smaller values at pressure forces of 1000N for example, which are typical for the spot resistance welding process.

Samples of diameter d=8 mm

In Table 3, respectively by diagrams in Fig.8 and Fig.9, the results for these samples are presented and illustrated. Same conclusions as for the samples with diameter 6mm can be derived.

Samples of diameter 10 mm

The results obtained for those samples are presented in Table 4 and illustrated in Fig.10 and Fig. 11 in an identical way as for the previous two cases. Here the influence of the measurement current on the conditioned samples is practically negligible.

Table 2

The contact resistance dependence on the pressure force applied - **d=6 mm**

F $[N]$			**100**	**200**	**300**	**400**	**500**
$I = 30\ A$	Surface untouched	R_k $[m\Omega]$	4,327	4,130	3,857	3,687	3,570
		S	0,166	0,159	0,217	0,265	0,300
	Surface conditioned	R_k $[m\Omega]$	1,443	1,173	0,967	0,850	0,717
		S	0,330	0,287	0,253	0,203	0,150
$I = 50\ A$	Surface untouched	R_k $[m\Omega]$	2,860	2,690	2,597	2,540	2,480
		S	0,159	0,105	0,045	0,053	0,072
	Surface conditioned	R_k $[m\Omega]$	1,243	1,023	0,880	0,790	0,700
		S	0,123	0,091	0,160	0,141	0,120

Table 3

The contact resistance dependence on the pressure force applied - **d=8 mm**

$F\ [N]$			**100**	**200**	**300**	**400**	**500**
$I = 30\ A$	Surface untouched	$R_k\ [m\Omega]$	4,527	4,147	3,923	3,703	3,640
		S	0,484	0,379	0,433	0,292	0,321
	Surface conditioned	$R_k\ [m\Omega]$	1,037	0,847	0,703	0,627	0,550
		S	0,206	0,183	0,165	0,162	0,154
$I = 50\ A$	Surface untouched	$R_k\ [m\Omega]$	2,977	2,770	2,620	2,553	2,470
		S	0,219	0,212	0,182	0,154	0,122
	Surface conditioned	$R_k\ [m\Omega]$	0,920	0,810	0,697	0,623	0,553
		S	0,173	0,131	0,145	0,143	0,140

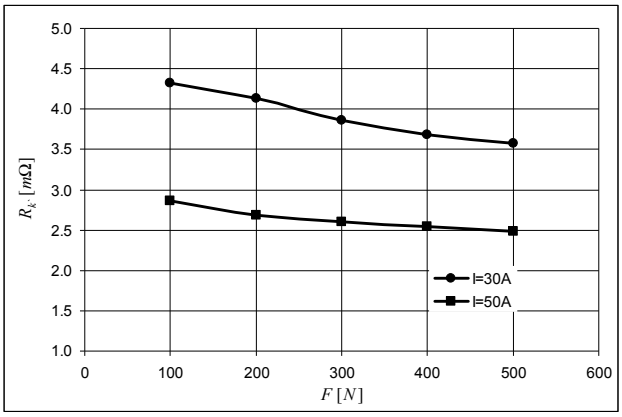

Fig.6. Relationship between the average value of the contact resistance and the contact pressure force – untouched samples (d=6 mm).

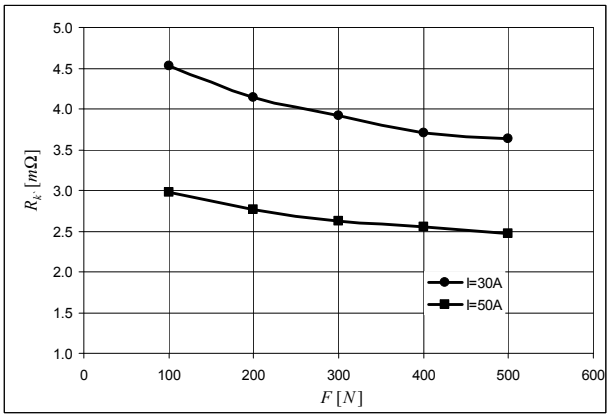

Fig.8. Relationship between the average value of the contact resistance and the contact pressure force– untouched samples (d=8 mm).

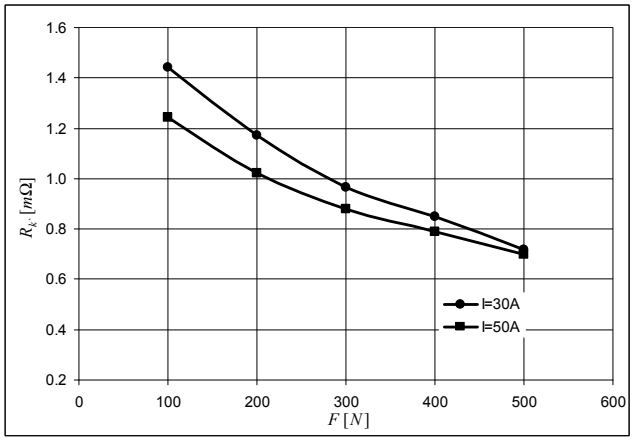

Fig.7. Relationship between the average value of the contact resistance and the contact pressure force – conditioned samples (d=6 mm).

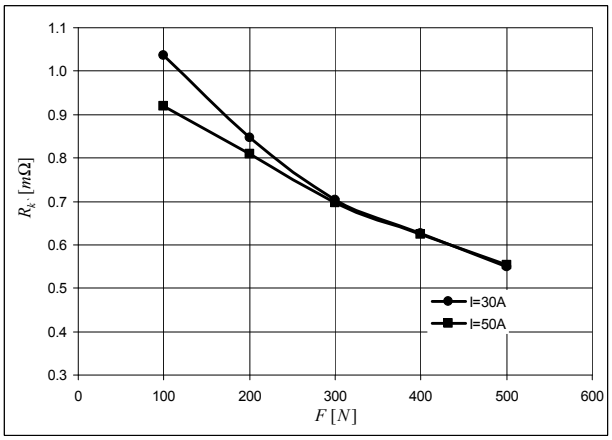

Fig.9. Relationship between the average value of the contact resistance and the contact pressure force– conditioned samples (d=8 mm).

Table 4

The contact resistance dependence on the pressure force applied - **d=10 mm**

F $[N]$			**100**	**200**	**300**	**400**	**500**
$I = 30\ A$	Surface untouched	R_k $[m\Omega]$	1,972	1,469	1,192	1,039	0,935
		S	0,537	0,259	0,234	0,194	0,200
	Surface conditioned	R_k $[m\Omega]$	0,572	0,499	0,412	0,352	0,299
		S	0,120	0,121	0,100	0,101	0,090
$I = 50\ A$	Surface untouched	R_k $[m\Omega]$	1,732	1,195	0,952	0,852	0,795
		S	0,410	0,228	0,104	0,062	0,031
	Surface conditioned	R_k $[m\Omega]$	0,599	0,505	0,412	0,355	0,302
		S	0,097	0,122	0,090	0,095	0,080

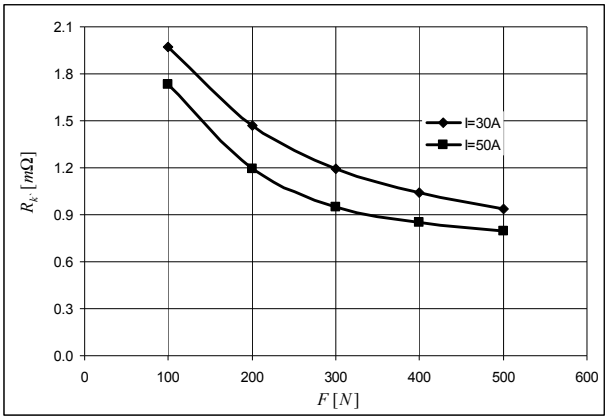

Fig.10. Relationship between the average value of the contact resistance and the contact pressure force – untouched samples (d=10 mm).

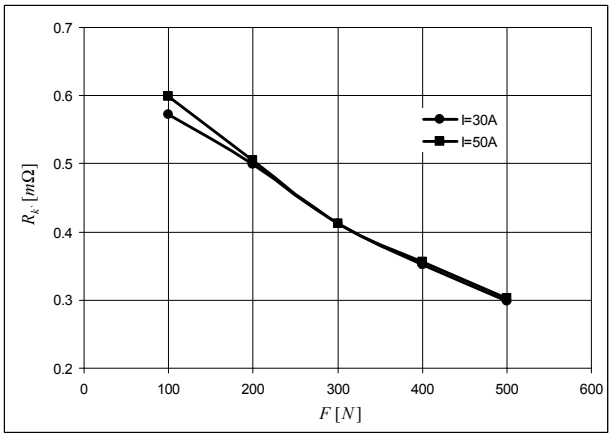

Fig.11. Relationship between the average value of the contact resistance and the contact pressure force– conditioned samples (d=10 mm).

Experimental results for the additional group investigations

The additional tests have been provided to check how the contact resistance is reflected by different surface conditioning of a sample. As it was shown above the difference may increase up to 3 times. Only samples having diameter of 8mm were investigated. Six different degrees of conditioning were realized as follows:

1. Untouched surface – no cleaning at all;
2. Degreased surface;
3. The surface scraped clean and then treated with skimmed liquid;
4. The surface brushed by sandpaper N:100 and then treated with skimmed liquid;
5. Surface conditioned for 1 min in sulfur acid solution of density 1,28;
6. Surface mechanically turned by lathe (superficial layer totally removed to reach the pure steel condition).

For each sample having one of those conditioned surfaces, 9 measurement of the contact resistance have been accomplished at pressure force 200 and 500N. The measurement current was kept always at a level of 40A. Each one of the 9 measurements set was practically individual as the contact spot was changed. This was done either by rotating or by axial displacement of both samples.

In Table 5 the obtained results for the average value of the resistance R_k $[m\Omega]$ are presented, again together with the calculated standard deviation S of each group of 9 measurements. In graphic form the results are illustrated in Fig. 12

Table 5

The contact resistance dependence on the surface degree conditioning - **d=8 mm**

Degree of surface conditioning		**1**	**2**	**3**	**4**	**5**	**6**
$F = 200\ N$	$R_k\ [m\Omega]$	5,314	3,674	2,917	1,020	0,959	0,850
	S	1,745	0,814	0,339	0,215	0,145	0,209
$F = 500\ N$	$R_k\ [m\Omega]$	3,760	2,967	2,309	0,559	0,596	0,559
	S	0,560	0,476	0,426	0,109	0,134	0,105

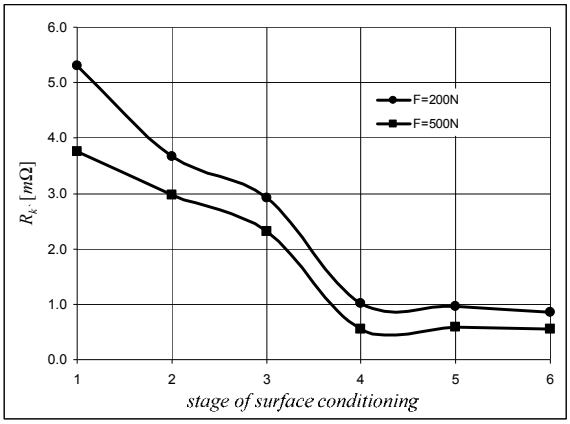

Fig.12. The average value of the contact resistance versus selected six degrees of surface conditioning.

Conclusions

1. The contact resistance R_k between two crossed cylindrical samples of reinforcing steel is important electrical circuit parameter for analyses of spot resistance welding processes. The experimental results obtained in the paper may serve as a useful tool for providing such kind of analyses.

2. At applied contact forces F of up to 500N the results for the investigated test samples having diameter of 6 to 10 mm follow the expected tendency of R_k to drop down when F increases. The reduction of R_k observed is not significant for the untouched sample's surface case, where the figures are in the range of 20% (samples 6mm) to 50% (samples 10mm). But for the conditioned samples the curve $R_k = f(F)$ was found to go down steeper and the reduction coefficient is of the order of 100%. This phenomenon can be explained by the substantial mechanical strength of the sample's superficial layer.

3. Specific are the results for the relationship of the contact resistance R_k versus the measurement current I. It was found that the resistance R_k diminishes when the current increases in the range up to 50 A, the effect being stronger for untouched sample surface. For the reported current range and at applied pressure force of 500N, resistance reduction figures of approximately 15-30% were noted.

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