EXPERIMENTAL STUDY OF THE RESISTANCE OF FLAT CU-W CONTACTS

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Abstract. The electrical resistance of several flat pieces of W-Cu-Ni pseudo-alloys contacts, with the different grain size distributions from 6 to 50 μm, prepared in various conditions of powder metallurgy, was measured. The obtained values being very dispersed in similar conditions, the dependence of the resistance on the pressing force was studied and the parameters of the well known formula for the constriction resistance as function of the pressing force was determined. The dependence of these parameters on the contact surface roughness statistical characteristics and the pressing force values are analyzed. Some theoretical models are verified.

Keywords: Contact, Pseudo-alloy, Resistance, Statistical distribution.

INTRODUCTION

The values of electrical contact resistance are very dispersed and difficult to predict, in spite of very simple theoretical formulas. In the paper, direct measurements of material resistivity, contact resistances and surface parameters were made and the theoretical explanation of the measured contact resistances are tried.

THEORETICAL MODEL OF THE CONTACT BETWEEN TWO FLAT SURFACES

We will replace like in [2] the real plane contact surfaces by a equivalent pair of plane surfaces, one absolutely smooth and an other roughish with uniform distributed N D_m – diameter spherical irregularities on each 1 cm² of plane contact surface area, having the

$$(1)\quad h_m = \frac{h_1 + h_2}{2}; \quad \sigma = \sqrt{\sigma_1^2 + \sigma_2^2}; \quad \sigma_i = \frac{h_{i\,max} - h_i}{3}; \quad D_m = \frac{D_1 \cdot D_2}{D_1 + D_2}$$

where the index 1 and 2 relate to the two surfaces (fig. 5).

The distribution of the random unevenness height will considered normal

$$(2)\quad f(z) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(z - h_m)^2}{2\sigma^2} \right)$$

The elastic force at the compression x will be [4]

$$(3)\quad P(x) = N\, E_m \sqrt{D_m} \int_{h_{max} - x}^{h_{max}} \left(\frac{z - h_{max} + x}{1.04} \right)^{3/2} f(z)\,\mathrm{d}z$$

The number of contact spots per 1 cm² and the radius of the constriction zone at the level z will be:

$$(4)\quad n(z) = N\left[\Phi\left(\frac{h_{max} - h_m}{\sigma} \right) - \Phi\left(\frac{z - h_m}{\sigma} \right) \right]; \quad r_1(z) = \frac{1}{2\sqrt{n(z)}}$$

The radius of mechanical contact spot of a D_m diameter spherical segment, having the height z, when the deformation is x will be

$$(5)\quad a(z,x) = \sqrt{(z + x - h_{max}) \cdot (D_m - z - x + h_{max})}$$

The constriction resistance of a singular contact spot with radius a, when the constriction area radius is r_1, is given in the Holm's book [1]

$$(5)\quad R(z,x) = \frac{\rho_1}{2\pi}\left[\frac{1}{a(z,x)} \operatorname{arctg} \frac{\sqrt{r_1(z)^2 - a(z,x)^2}}{a(z,x)} - \frac{\sqrt{r_1(z)^2 - a(z,x)^2}}{r_1(z)^2} \right]$$

The conductance and the resistance of multispot contact per 1 cm^2 of contact surface, for the deformation x is given by previous formula and the distribution of the random irregularities height:

$$(7) \quad G(x) = N \int_{h_{max}-x}^{h_{max}} \frac{f(z)}{R(z,x)} dz; \qquad R_1(x) = \frac{1}{G(x)}$$

THE CASE OF UNIFORM DISTRIBUTED UNEVENNESS HEIGHT

In the case of uniform distribution of the unevenness height the integrals (3) and (7) can be calculated and the results are the following

$$(8) \quad f_0(z) = \frac{1}{h_{max}} \Rightarrow P(x) = A \cdot x^{2.5}; \; G(x) = B \cdot x^{1.5} = B\left(\frac{P}{A}\right)^{0.6}$$

$$A = 0.377 \frac{N}{h_{max}} E_m \sqrt{D_m}; \; B = \frac{8}{3} \frac{N}{h_{max}} \frac{\sqrt{D_m}}{\rho_1}$$

The variation of the multispot contact resistance versus the pressing force can be represented as follows

$$(9) \quad R_0 = \frac{c_0}{P^m}; \quad c_0 = \frac{A^{0.6}}{B}; \quad m = 0.6$$

The exponent m is independent on the number of contact spots but depends on the unevenness shape and their height distribution. In fig. 2 the values of this exponent are given for spherical unevenness and normal height distribution versus the maximum rapprochement of contact members and the coefficient of variation as a parameter. In fig. 3 the same exponent is given for various values of the ratio between the maximum and average value of the unevenness height. (x_1 is the smallest value of rapprochement for which the exponent m is determined).

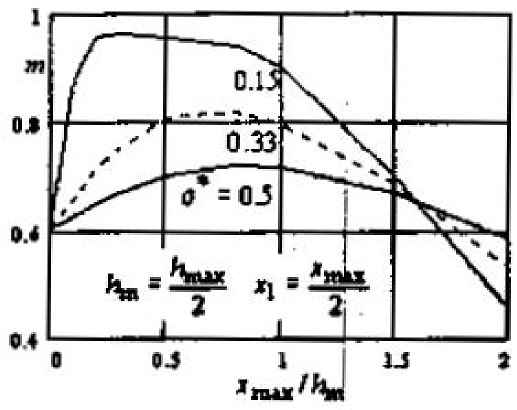

Fig. 2 Exponent m *versus the contacts rapprochement*

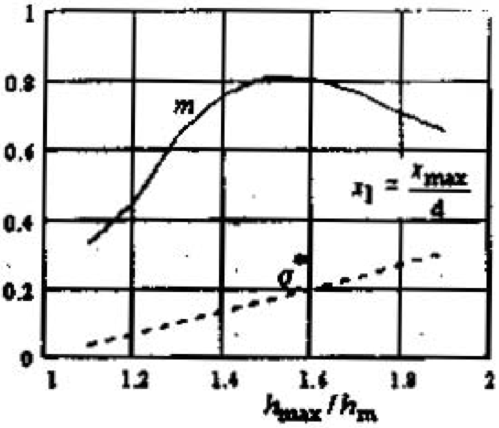

Fig. 3 Exponent m *versus the unevenness heights ratio*

EXPERIMENTAL RESULTS

The setup of the measurement scheme is given in fig. 4.

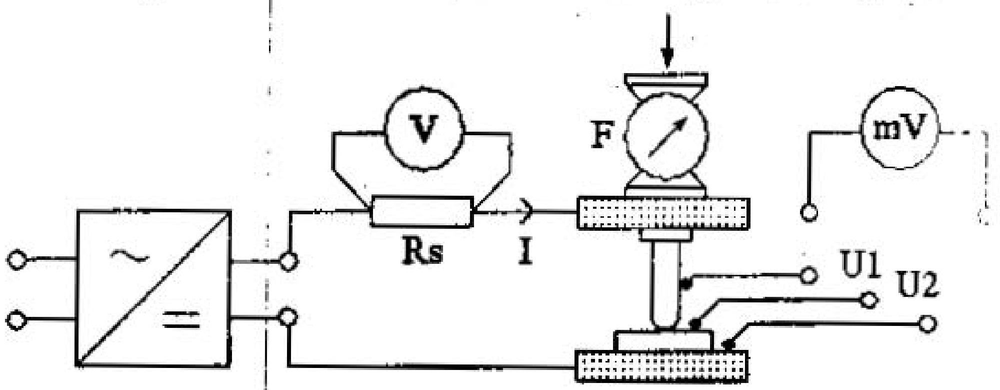

Fig. 4 The measurement scheme

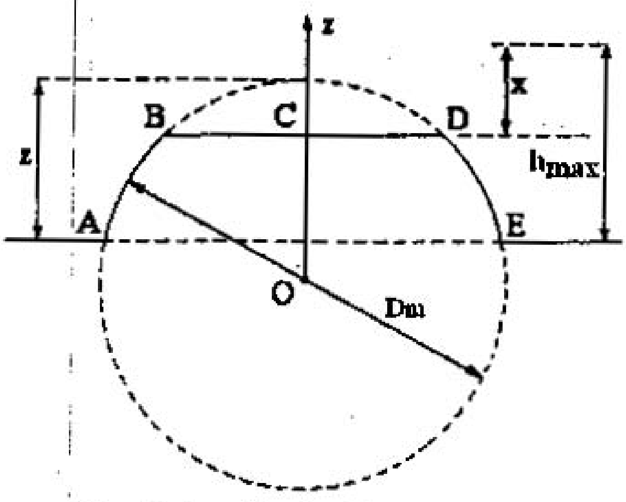

Fig. 5 A spherical unevenness

A sample of roughness diagram is shown in fig. 6.

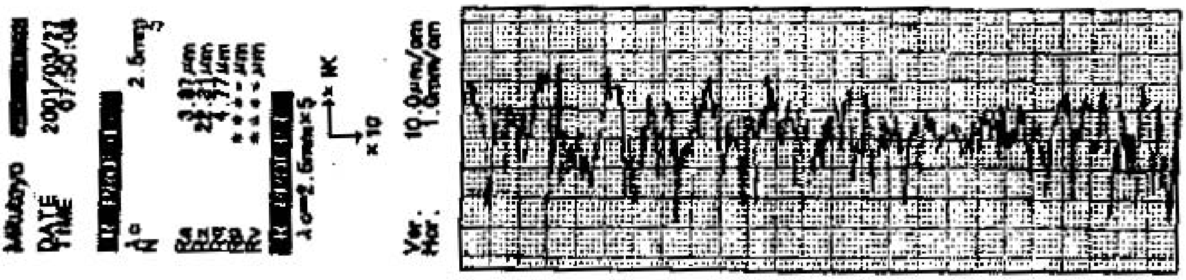

Fig. 6 A sample of roughness diagram

The material granulation, the compression force, the sintering temperature and environment and the values of the calculated coefficients m_1, c_1, m_2, c_2, the values of measured contact resistance R_1 and R_2 and the average, maximum and standard deviation roughness of the two surfaces of the tested contact members, are given in table 1.

The experimental values of the parameter c_1, m_1 and c_2, m_2 from formula (9) are given in fig. 7 and 8.

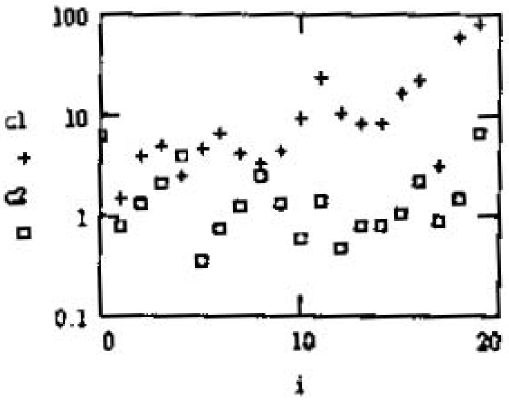

Fig. 7. The coefficients c for the two contacts

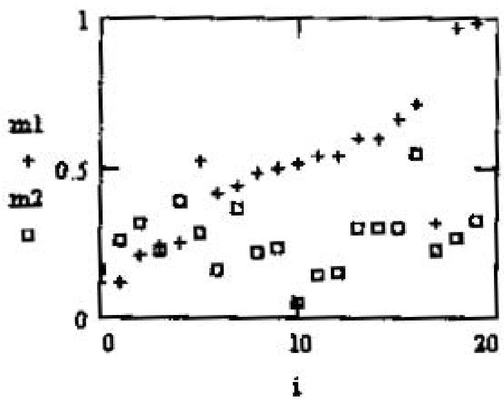

Fig. 8. The exponents m for the two contacts

In fig. 9 and 10 are shown the dependency $R_1=f(F)$ and $R_2=f(F)$ for the contact members 231 and 241.

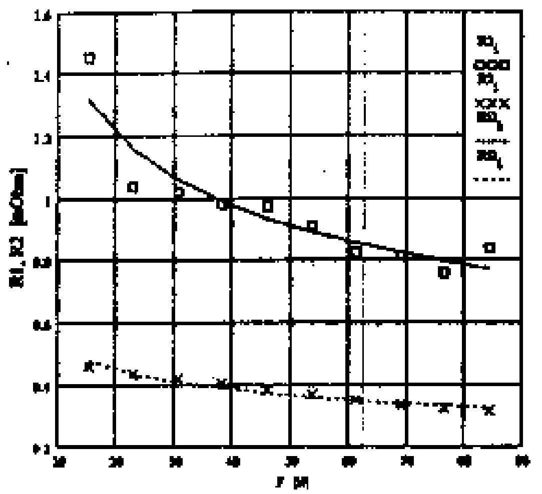

Fig. 9 Dependency $R_1=f(F)$ *and* $R_2=f(F)$ *for 231*

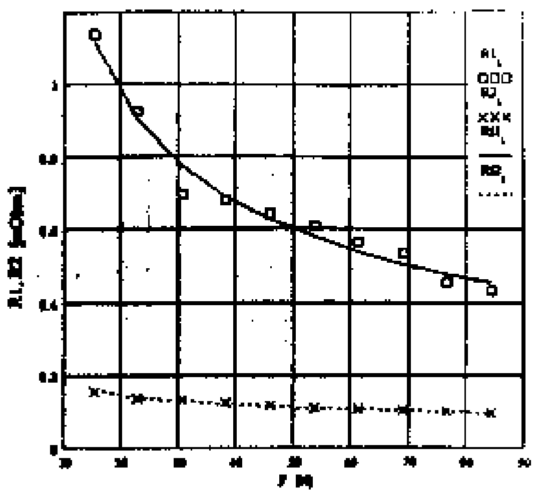

Fig. 10 Dependency $R_1=f(F)$ *and* $R_2=f(F)$ *for 241*

In the next table the following notation of the roughness parameters are used:

- *ra* is the arithmetic mean of the absolute values of the profile variations from the mean line;
- *rz* is the ten-point height of irregularities;
- *rq* is root-mean-square deviation of the profile and the grain... are the following:

G1 = 100% W > 50 μm;
G2 = 70% W > 50 μm + 30% W8 ÷ 20 μm;
G3 = 70% W > 50 μm + 30% W6 ÷ 12 μm;
G4 = 100% W 6 ÷ 12 μm.

The correlation matrix of some parameters from tab. 1 is given in table 2. A large correlation was stated also between m_1 and c_1 (0.78) and very small between m_2 and c_2 (0.15).

Table 1. Experimental results

No.	G	F sint [tf/cm2]	Env.	T sint [°C]	c_1	m_1	c_2	m_2	R_1 [mΩ]	R_2 [mΩ]	ρ [μΩ m]	ra_1 [μm]	rz_1 [μm]	rq_1 [μm]	ra_2 [μm]	rz_2 [μm]	rq_2 [μm]
332	G2	3	H	1250	10.637	0.12	6.339	0.158	0.2719	0.2952	0.0563	0.47	3.96	0.61	3.47	18.40	4.19
141	G1	4	H	1250	1.527	0.123	0.781	0.262	0.5105	0.2171	0.0573	0.39	2.77	0.49	3.96	26.31	5.15
362	G2	6	V	1350	4.016	0.212	1.339	0.316	0.2663	0.0791	0.0580	0.71	10.91	1.31	1.45	18.16	2.79
262	G3	6	H	1250	4.997	0.237	2.104	0.224	0.3728	0.1237	0.0600	0.63	6.39	0.89	3.05	16.95	3.72
132	G1	3	V	1350	2.448	0.252	3.929	0.390	0.361	0.146	0.0530	0.79	6.69	1.14	2.97	17.22	3.70
331	G2	3	H	1250	4.700	0.526	0.346	0.282	0.256	0.058	0.0576	0.76	6.99	1.11	5.78	31.04	7.22
242	G3	4	V	1350	6.871	0.424	0.775	0.159	1.649	0.099	0.0750	0.49	6.57	0.82	3.08	19.57	3.89
342	G2	4	H	1250	4.202	0.438	1.287	0.363	1.108	0.110	0.0599	0.35	3.14	0.51	2.92	18.65	3.61
341	G2	4	H	1250	3.268	0.482	2.485	0.220	0.419	0.169	0.0585	0.58	8.44	1.02	3.87	22.31	4.77
431	G4	3	V	1350	4.555	0.504	1.345	0.237	0.761	0.080	0.0700	*	*	*	*	*	*
165	G1	6	V	1350	9.491	0.517	0.607	0.047	1.106	0.032	0.0630	0.89	5.74	1.10	3.62	21.80	4.52
145	G1	4	V	1350	24.122	0.537	1.420	0.140	2.022	0.034	0.0580	*	*	*	*	*	*
261	G3	6	V	1350	10.687	0.543	0.474	0.147	1.913	0.061	0.0600	0.71	5.36	0.90	3.44	19.30	4.18
412	G4	1.5	H	1250	8.414	0.597	0.799	0.297	1.156	0.876	0.0663	0.92	6.67	1.16	2.92	19.66	3.75
421	G4	2	V	1350	8.414	0.597	0.799	0.297	0.689	0.204	0.0800	0.26	2.00	0.33	3.04	18.97	3.77
411	G4	1.5	V	1350	16.565	0.670	1.036	0.301	0.493	0.060	0.0530	0.26	2.10	0.34	3.78	23.64	4.69
241	G3	4	H	1250	21.877	0.724	2.217	0.548	0.784	0.032	0.0400	1.46	9.14	1.80	3.33	19.10	4.06
231	G3	3	H	1250	3.096	0.313	0.890	0.226	0.852	0.228	0.0660	*	*	*	*	*	*
422	G4	2	V	1350	58.628	0.974	1.504	0.263	1.417	0.029	0.0600	0.51	4.79	0.76	2.89	18.72	3.63
161	G1	6	H	1250	78.523	0.978	6.552	0.322	0.312	0.084	0.6590	0.46	3.22	0.57	3.79	24.66	4.87

Max.	78.52	0.98	6.55	0.548	2.02	0.88	0.66	1.46	10.91	1.80	5.78	31.04	7.22
Avg.	14.35	0.49	1.85	0.26	0.84	0.15	0.09	0.63	5.58	0.87	3.37	20.85	4.27
σ	19.3	0.23	1.73	0.10	0.56	0.19	0.13	0.30	2.54	0.38	0.85	3.73	0.96
σ*	1.34	0.48	0.94	0.40	0.67	1.24	1.48	0.47	0.45	0.44	0.25	0.18	0.22

Table 2

	G	F	T	ρ	ra_1	rz_1	rq_1	ra_2	rz_2	rq_2
c1	**-0.04**	0.09	0.01	-0.01	-0.07	-0.24	-0.15	0.02	0.09	**0**
m1	**0.31**	-0.15	0.14	0.06	0.08	-0.17	-0.02	0.15	0.16	**0.08**
c2	**-0.37**	0.14	**-0.30**	-0.19	-0.06	-0.10	-0.09	-0.02	-0.14	**-0.07**
m2	0.14	-0.24	-0.29	**-0.44**	**0.32**	0.16	**0.30**	-0.13	-0.06	-0.10

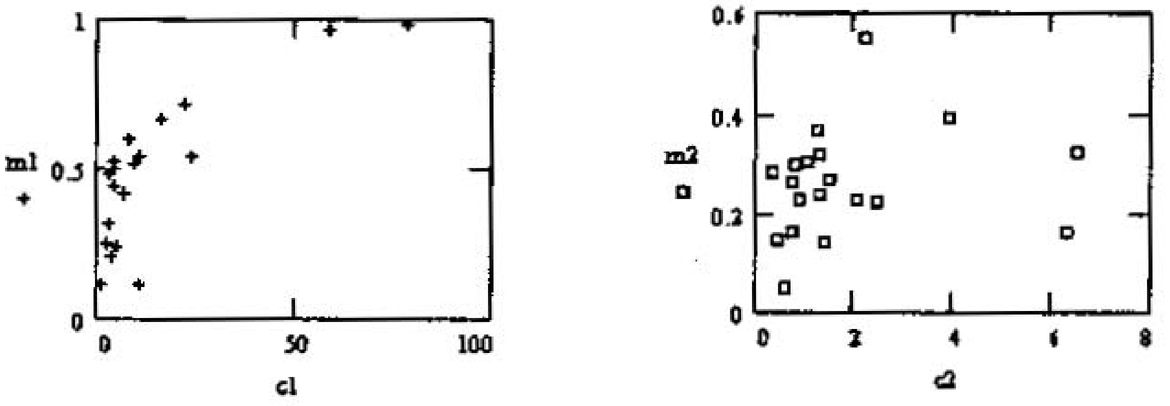

Fig. 11. Exponents m versus the coefficients c

CONCLUSIONS

Theoretically the contact resistance is given by the formula (9), where the exponent *m* is equal to 0.33 for elastic deformation and 0.5 for plastic deformation [1]. This result fit satisfactory (in spite of large variance) with experimental data in the case of sphere-plane contact (fig. 7, tab. 1), for upper contact in fig. 4. In the case of flat contact surfaces the experiment shows that the exponent *m* is often much less than 0.33. The mean value is 0.26, with smaller variance. This fact can not be explained by statistical theory, which considers the unevenness height normal or uniform distributed. For this distribution the resulting values of *m* are, generally larger than 0.33 (fig. 2 and 3).

The sintering compression force has no influence on the contact resistance. The exponent *m* in the case of sphere-plane contact has a small dependency on the granulation level (correlation = 0.31) and is independent on the surface irregularities and material resistivity, while in the case of flat contacts there is a small dependency on the mean irregularities height (corr.= 0.32) and on the resistivity (corr.=-0.4[illegible]). The coefficient c_2 can depend on granulation (corr.=-0.37) sintering temperature (corr.=-0.3)

REFERENCES

[1] Ragnar Holm, *Electric Contacts*, 4-th ed., Springer-Verlag, Berlin/Heidelberg/New York, 1967.

[2] E. I. Kim, V. T. Omelchenko, S. N. Harin, *Mathematical models of thermal processes in electric contacts*, (in Rus.), Nauka, Alma Ata, 1977.

[3] Desmond F. Moore, *Principles and applications of tribology*, Pergamon Press, Oxford, 1975.

[4] S. V. Serensen (ed.), *Machines design handbook, (Spravochnik mashinostroitelea)* vol. 3 and 6, (in Rus.), Mashgiz, Moscow, 1955.

[5] Y. V. Koritskii, V. V. Pasynkov, B. M. Tareev, *Electric materials handbook*, vol. 3, (in Rus.), Energoatomizdat, 1988.