THE EFFECT OF COLD DEFORMATION AND HEAT TREATMENT ON COEFFCIENT OF STRAIN RESISTANCE①

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ABSTRACT

The coefficient of strain resistance for metals, solid solutions and ordering alloys in annealing state decreases, while K increases in cold working state. The value K of pure metals and solid solutions invariably decreases with temperature increase. The main factors influencing the coefficient of strain resistance are crystal defect, dispersion and degree of atomic arrangement.

Key words: platinum-base alloys, gold-base alloys, coefficient of strain resistance multicomponent alloys.

1 INTRODUCTION

The electric resistance of metal material which changes while tensioned or pressured, is called strain resistance effect. There is a proportional relationship between relative variation of resistance, $\Delta R / R$, and strain ε and their ratio is the coefficient of strain resistance K. By means of K, mechanical quantity can be transfered into electrical quantity. The larger the value of K the more sensitive the sensor. The value of K depends upon the characteristics of the material and its alloy state. Coefficients of strain resistance for metals and alloys have been studied by Bertodo[1], Hakru Masumoto[2], and the author[3]. Since the effect of cold deformation and heat treatment on the coefficient of strain resistance has not been investigated so far, it would be useful to study the question systematically.

2 EXPERIMENT

A device which consists of tongs, leads, a frame, a clock gauge and screw is designed to measure the resistance variation of metal wire or strip during deformation. The specimen is held between two tongs 267.22 mm apart, and as far apart as 648.74mm for metals with lower resistivity. The specimen is tensioned by tightening the screws and the length is measured by clock gauge. Both ends of the tongs are welded with ampere and potential leads. The resis- tance variation of the specimen during tension is measured by QJ−19 Kelvin Bridge.

GY−700 Measuring Machine of High Temperature Strain Gauge and UCAMW−8 BL multi-digital apparatus were used for measuring the coefficient of strain resistance of a single wire gauge at different temperatures. The adhesive used is P_{122}, which is treated at

700℃ for 1h stabilization.

A hardening state means that the working state for section reduction ψ is larger than 80% and the annealing state means that the specimen is treated with recrystallization annealing or high temperature stabilization.

3 RESULTS

3.1 Coefficient of Strain Resistance at Room Temperature

The relative resistance variation of metal wire during deformation is measured by a self-made strain resistance device, and the values of K for different ε are calculated. The relation between K and ε is shown in Fig.1. The value of K within the range of elasticity would be constant, otherwise it would decrease obviously. The value of K for pure metals and solid

solution alloys tends to 2 when ε is high enough.

The coefficient of strain resistance K and resistivity ρ for specimen of annealing and hardening at room temperature are listed in Table 1.
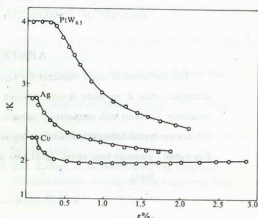

Fig.1　K versus ε

Table 1　The coefficient of strain resistance K and resistivity ρ

metal	annealing state		hardening state	
	K,	ρ,$\mu\Omega \cdot$ cm	K	ρ,$\mu\Omega \cdot$ cm
Pt	4.87	10.5	5.57	
Ag	3.08		3.52	
Al (Al$_2$O$_3$)	2.24		2.34	
Cu	2.31		2.39	
PtRh$_{13}$	4.08	20.5	5.53	20.8
PdW$_{20}$	2.64	110.0	2.98	104.2
PdNi$_{25.3}$Cr$_{9.6}$	2.26	4.3	2.53	71.6
PtCu$_{8.5}$	1.39	54.4	1.69	60.3
PdAu$_{42}$Fe$_{11}$	1.70	182.0	3.26	62.8
PdAu$_{38}$Fe$_{11}$Al$_1$	1.85	211	2.97,	67
PdFe$_{16}$Cr$_5$Al$_1$	2.84	89.5	2.26	83.2
AuCu$_{14}$Ag$_{10}$Pt$_5$Ni$_1$	2.01	16.2	1.50	20.4
PdAg$_{30}$Cu$_{14}$Au$_{10}$Pt$_{10}$Zn$_1$	3.01	20.4	1.92	33.1

3.1.1 Pure Metals and Solid Solution

It can be seen from Table 1 that K and ρ decrease during recrystallized annealing for pure metals and solid solutions, while they increase during cold deformation. For heterogenous solid solutions (such as PdW$_{20}$) the

same behaviour can be observed except the resistivity decreases upon hardening.

3.1.2 Ordered Alloys

For normal ordered Pt–8.5Cu the variations of K and ρ caused by cold deformation and heat treatment are the same as for pure

metals and solid solution alloys, but the variations are more obvious. For alloys of Pd−35Au−11Fe−1Al and Pd−42Au−11Fe, the variation is different[4]. The values of K decrease but ρ increase when the long range order occurs after proper heat treatment. The value of K for alloys Pd−42Au−11Fe in quenching state is larger than that in annealing state because of the short range order formed by quenching.
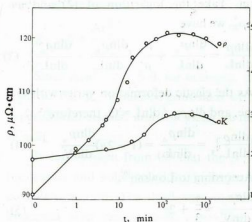
Fig.2   Variation of K & ρ for hardening alloy ageing at 500℃

3.1.3   Phase Discomposition Alloys

For alloys of Pd−10Fe−5Cr−1Al, Au−14Cu−10Ag−5Pt−1Ni and Pd−30Ag−14Cu−10Au−10Pt−1Zn, the second phase is precipitated during isothermal ageing, as the phase transformation belongs to the mechanism of nuclear growth. They have lower K values at quenching and hardening states. However, K and ρ increase during isothermal ageing, and the typical curves are shown in Fig.2 where the curve of K−t is similar to that of ρ−t. K and ρ reach a maximum value after incubation. The ratios of ρ−t and K−t for Cu−38Pt alloy treated at 300℃ are shown in Fig.3, which shows that ρ decreases in the primary 20 min and then becomes smooth. But the ratio of K−t is the opposite. The decrease of ρ can be explained by Spinodal ordered discomposition[5].
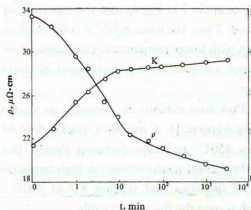
Fig.3   Variation of K and ρ for hardening alloy Cu−38pt ageing at 300℃
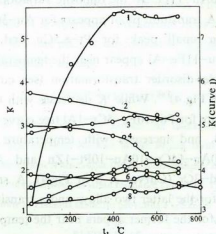
Fig.4 K versus T for metals and their alloys
1—Fe;   2—PtW;   3—PtAgCuAuPtZn;
4—PdFeCrAl;   5—AuCu;   6—PtCu;
7—PdAuFeAL;   8—AuPdCr

3.2   High Temperature Coefficient of Strain Resistance

The coefficients of strain resistance for several single wire gauges made of typical metals and alloys are measured at different temperatures (see Fig. 4). The value of K is not constant at elevated temperatures and

becomes more complex.

Normally, the value of K for solid solutions decreases with the increase of temperature(see curve 2 in Fig.4), and the repeatability is good. Thus, the wires made of solid solution alloys with lower temperature coefficient of resistance are used for a sensitive grid of strain gauge.

Pure iron exhibits an anomaly, as shown in Fig.4 (curve 1). K increases quickly to 7.64 below 450℃ and then decreases slowly. But for the second measurement at high temperature K increases and reaches 8.7 at 300℃, which is over the theoretical value.

For alloys of Au–30Cu and Pt–8Cu K increases with the temperature, while for Pd–38Au–11Fe–Al the opposite variation occurs. A transition point appears for Au–30Cu and a small peak for Pt–8.5Cu and Pd –38Au–11Fe–Al appear near the temperature of order-disorder transformation (see curves 5–7 in Fig.4).[4]. While K decreases with temperature for Pd–10Fe–5Cr–1Al (see curve 4 in Fig.4), and increases with temperature for Pd–30Ag–14Cu–10Au–10Pt–1Zn and Au– 38.6Pd–3Cr (Curves 3, 8 in Fig.4). A small peak for the latter two alloys and a transition point for the former apperars near the temperature of phase discomposition.

4 DISCUSSION

The coefficient of strain resistance K under monodirectional tension can be described as:

$$K = \frac{\mathrm{d}\ln R}{\mathrm{d}\ln L} = (1 + 2\mu) + \frac{\mathrm{d}\ln\rho}{\mathrm{d}\ln L} \quad (1)$$

where, R and L–resistance and length of specimen: μ–Poisson ratio: the first term $(1+2\mu)$ represents the geometric effect: the second term $\mathrm{d}\ln\rho / \mathrm{d}\ln L$, physical effect. The

value of μ is about 0.35 for most metals. Therefore, the value of K depends mainly on $\mathrm{d}\ln\rho / \mathrm{d}\ln L$.

As large amounts of the crystal defects are formed during cold deformation, the resistivity increases as follows:

$$\rho = \rho_o + \rho_R = \rho_o(1 + \frac{\rho_R}{\rho_o}) \quad (2)$$

where, ρ_o–resistivity at annealling state: ρ_R–remained resistivity after cold deformation. Take the logarithm of (2) and as $\rho_o \gg \rho_R$, we have

$$\frac{\mathrm{d}\ln\rho}{\mathrm{d}\ln L} = \frac{\mathrm{d}\ln\rho_o}{\mathrm{d}\ln L} + \frac{\rho_R}{\rho_o}[\frac{\mathrm{d}\ln\rho_R}{\mathrm{d}\ln L} - \frac{\mathrm{d}\ln\rho_o}{\mathrm{d}\ln L}] \quad (3)$$

As the elastic deformation varies with the volume, and $\mathrm{d}\ln\rho_R / \mathrm{d}\ln L = O$, therefore:

$$[\frac{\mathrm{d}\ln\rho}{\mathrm{d}\ln L}]_e = \frac{\mathrm{d}\ln\rho_o}{\mathrm{d}\ln L} = (1 - 2\mu)\frac{\mathrm{d}\ln\rho_o}{\mathrm{d}\ln V} \quad (4)$$

According to Lowsen[6]:

$$\frac{\mathrm{d}\ln\rho_o}{\mathrm{d}\ln V} = \frac{2}{3} + 2\gamma \quad (5)$$

where V–volume of specimen: γ–Grunison constant. As no change in volume occurs in plastic deformation:

$$\frac{\mathrm{d}\ln\rho_o}{\mathrm{d}\ln V} \to 0$$

thus:

$$[\frac{\mathrm{d}\ln\rho}{\mathrm{d}\ln L}]_p = \frac{\rho_R}{\rho_o}\frac{\mathrm{d}\ln\rho_R}{\mathrm{d}\ln L} = \frac{\mathrm{d}\rho_R}{\rho_o\varepsilon} \quad (6)$$

It has been pointed out by Buereh[7], Broonm[8], and Pieffer[9]that:

$$\mathrm{d}\rho_R = A\varepsilon^B \quad (7)$$

where A is a constant depending on the concentration of impurities and primary state; B is a constant, (regarded as 1 for Al and Mo, 3/2 for Cu, Ag and Au, and 3/4 for metals with higher strain) K for cold deformation metals is the sum of elastic and plastic

deformation:

$$\frac{d\ln\rho}{d\ln L} = [\frac{d\ln\rho}{d\ln L}]_e + [\frac{d\ln\rho}{d\ln L}]_p$$

$$= (1 - 2\mu)(\frac{2}{3} + 2\gamma) + \frac{A\varepsilon^{B-1}}{\rho_o} \quad (8)$$

Combine equations (8) and (1):

$$K = (1 + 2\mu) + (1 - 2\mu)(\frac{2}{3} + 2\gamma) + \frac{A\varepsilon^{B-1}}{\rho_o} \quad (9)$$

In case of plastic crystal deformation $\mu = 0.5$, so we have:

$$K_\rho = 2 + \frac{A\varepsilon^{B-1}}{\rho_o} \quad (10)$$

Since $A\varepsilon^{B-1} / \rho_o > 0$, for example, if it is 0.01 for Cu, K_ρ would be consistent with the experimental results, and for metal materials, $K_\rho \approx 2$.

It can be seen from (9) that the K value for metals and solid solutions increases after cold deformation. The third term in (9) may disappear after recrystallized annealing, and K decreases, especially for the alloys with irregular arrangement of atoms.

It is known that the relationship among Gruneison constant, and the thermal expansion coefficient β, the specific heat capacity of constant volume C_v, the bulk module of elasticity E and the density d is $\beta E / C_v d$.

According to Gruneison's law, the ratio of $\beta / C_v d$ is independent from temperature, while E is dependent on temperature. Thus, the K of normal metals and alloys, as well as module of elasticity decrease with temperature. A noncontinuous transition of β, C_v, E and d occurs near phase transformation temperature, leading to be mutations of r and K. The abnormal behaviour of K for iron may be caused by ferromagnetism. The dispersion matter produced from phase discomposition alloy

during its isothermal ageing has a thening effect, and leads to the increases of E as well as γ and K.

5 CONCLUSION

1 The coefficient of strain resistanace K for metals, solid solutions and ordered alloys decreases by recrystallized annealing, but increases by cold working.

2 The value of K for phase discompositon alloys by isothermal ageing or annealing is higher than that obtained by hardening.

3 K obviously decreases for alloys with long range order, increases for alloys with short range order, with dispersion precipitating phase or with crystal defects.

4 K of solid solutions decreases with the increase of temperature. Abnormal behaviours occur in some phase transformation alloys and ferromagnetic metals.

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