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ON THE RELATION BETWEEN CRYSTALLOGRAPHIC TEXTURE AND MECHANICAL PROPERTIES OF SOME F.C.C. METALS

A.M. El-Shabiny, N.A. Ahmed, F.A. Saadallah and M.A. Belal
Solid State Physics Department, National Research Center, Dokki, Cairo, Egypt.

Abstract:

Commercially used wires of copper, silver and aluminium were cold drawn to different values of reductions in cross-sectional area with and without preannealing. Using X-ray diffraction analysis, it was found that all the samples exhibit high preferred oreintation. The crystallographic texture of the samples was determined quantitatively by the inverse pole figure. The <111 > orientation increases with the increase of reduction in cross-sectional area and preannealing. The general increase of the degree of the <111> orientation from silver to copper to aluminium is explaiend in terms of the increase of the stacking -falut energy. The yield and ultimate tensile stresses were affected by both the texture and the crystalite size. However, the values of the elastic modulus were found to depend essentially on the crystallographic texture of the wires.

Introduction

Deformation of f.c.c. metals occures by slip in the densest close-packed {111} planes and in the close-packed <110> directions. During deformation, there is a tendency for the grains to rotate under the applied tensile deformation, so that the slip system {111} <110> is oriented for easy flow. Simple wire texture consists of an orientation that have a particular crystallographic direction parallel to the axis of the wire and other directions distributed with equal probability around the wire axis, giving rotational symmetry. In general case, f.c.c. metals upon drawing contain doplex <111> + <100> fiber texture.

The practical importance of the preferred orientation lies in the variation in properties with the direction. A specimen with a preferred orientation will have directional or anisotropic properties, which will be desirable or undesirable, depending upon the intended use of the material. The modulus of elasticity, E, of f.c.c. metals as examples, is greater in the crystallographic direction <111> than the other directions(1).

Textures in high-purity materials may be different from those in materials of ordinary purity, which results from different deformation mechanisms(1,2). Changes of the texture of metallic wires can occur at low temperature of annealing. Texture resulting from annealing have been studied extensively because of their influence on the directionality of properties in the finished products and of their scientific interest. The object of the present work is to study the effect of plastic deformation (cold drawing) and pre-annealing on the type and degree of preferred orientation of Egyptian product Cu-, Ag- and Al-wires. Also, a correlation between their crystallographic tesxture and mechanical properties will be considered.

Experimental and Calculations

Copper, aluminium and silver rods of 5 mm diameter were supplied by "Helwan Company for Non-ferrous Industries" and the "Egyptian Mint House". The rods were cold drawn in one direction, without any heat treatment, using successive dies to diameters of 2.0, 1.7, 1.5 and 1.0 mm giving deformations of 84%, 88%, 91% and 96%, respectively.

Another series of the three metals were pre-annealed before deformation. The copper and aluminium rods were annealed at 150°C and that of silver at 220°C for 7 hours. The Cu-rods were covered by a copper foil. After the pre-annealing, the rods were cold drawn to the same diameters mentioned above.

Samples were prepared for X-ray diffraction examination by cutting the wires in sections perpendicular to the wire after filling their surface to a hexagonal shape. More than twenty pieces were stuck

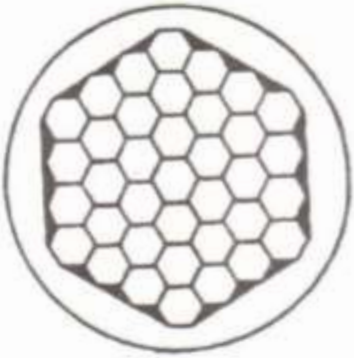

Fig. (1): Sample surface of stuck together hexagonal cross-section wires.

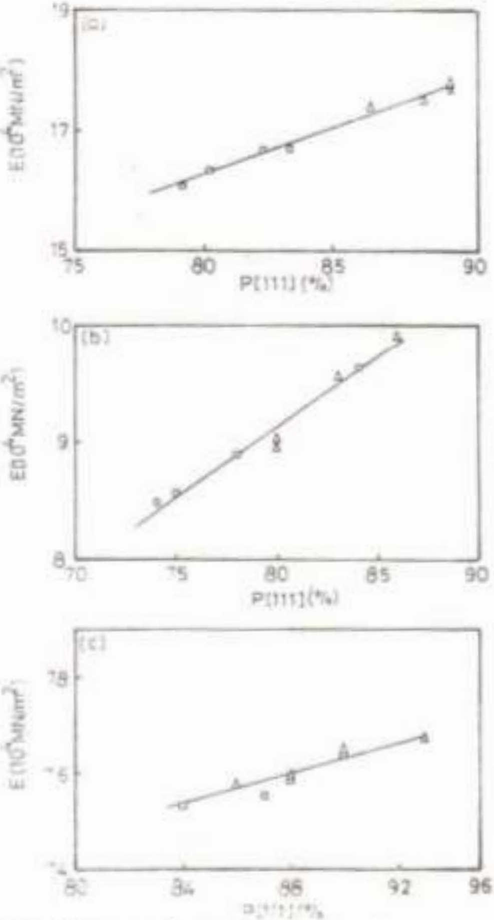

Fig. (2): Variation of degree of preferred orientation as a function of degree of deformation : (a) Cu, (b) Ag and (c) Al (Δ with and ❑ without preannealing).

together with cold resin to give a sample of nearly circular shape of reasonable area (Fi.g 1). The hexagonal shape is the proper one to minimize the gaps in between the pieces. All samples were polished by successive fine abrasives while cooling by water, then etched by the suitable reagents. The specimens were washed carefully by distilled water and ethyl alcohol then dried and coated by very thin transparent polymer layer. The random samples were prepared by filling the samples to powder passed from 300 mesh sieve. The powder was then slightly pressed in the form of a disc (12 mm diameter and 3 mm thickness) and annealed at 400°C for 4 hours.

Using monochromatic Cuk α-radiation, the diffraction pattern of all the specimens were obtained. The (hk1) reflections were recorded by a slow scanning speed (2°/min) to attain accurate intinsity values. For the random samples, the relative integrated intensities were found to be in good agreement with those calculated theoretically. The type and degree of preferred orientation were claculated using the inverse pole figure method. The pole densities were calculated using the equations:

$$P\,(nkl) = \frac{I_s\,(hkl)}{I_r\,(hkl)} \Big/ \frac{1}{n} \sum \frac{I_s\,(hkl)}{I_r\,(hkl)}$$

where P is the pole density of the rational index parallel to the wire axis compared to that of the random sample. The pole deusity of <111> and <100> directions were calculated as follows:

$$P\,[111] = 1/2\ [P\langle 111\rangle + P\langle 222\rangle]$$

and

$$P\,[100] = 1/2\ [P\langle 200\rangle + P\langle 400\rangle]$$

The percentages of <111> direction were calculated from:

$$P\,[111]\,\% = \frac{P\,[111] \times 100}{P\,[111] + P\,[100]}$$

The Instron 1128 machine was used to determine the mechanical properties of the wires at room temperature: the elastic (Young's) modulus (E), the yield stress (Y.S.) and the ultimate tensile stress, (U.T.S.).

Results and Discussion:

The values of the structural properties, that are the pole densities of [111] and [100] textue as well as the percentage of [111] direction, are given in Table (1). The values of pole densities of the other directions are less than 0.3. Fig. (2) shows the relation between the applied deformation and the percentage of <111> fiber texture of the three types of wires with and without preannealing. The curves show a continuous increase of the <111> orientation with the increase of the reduction in area. The increase of the <111> texture by drawing was found by many authors(3). It is clear that the effect of preannealing on the three metals is the increase of the <111> texture as a general behaviour. The dependance of the developed texture on annealing was reported by Inakazu and Yamamoto(7), who found that copper wires drawn to 95% and intermidiatly annealed at 240°C and then cold drawn developed <111> texture.

The percentage of <111> orientation increases as we go from silver to copper to aluminium. This can be explained in terms of the stacking fault-energy. Stacking - fault energies make cross slip easier and appeared to be a fundamental variable controlling the relative amounts of [111] and [100] components, however, the correlation is not simple(4). Cross-slip is thought to be responsible for reorientation into [111] texture. On the other hand, mechanical twining can cause reorientation out of [111] into near [100](1) . Ahborn and Wassermann(5) explained the rotation towards the <100> orientation in case of sliver as due to mechanical twining. According to Christian and Swan(6), the stacking fault energy of sliver is much lower than that of aluminium. With a lower-stacking fault energy, there is a lower tendency to cross slip and consequently <100> texture is more likely to form in grater amount at the expense of the <111> component.

The results of the mechanical properties are summarized in Table (2). Figs. (3-5) show the variation of the different mechanical properties with the texutre of the samples. It is clear that the values of the properties for the three metals increase with the increase of the [111] orientation indicating the great dependence on crystallographic texture. This is also a prove of the fact that the value of E<111> is greater than that of E<100> for the three metals. Inakazu and Kawamoto(8) similarly found that the aluminium wires having the <111> axial orientation show the highest values of mean tensile strength.

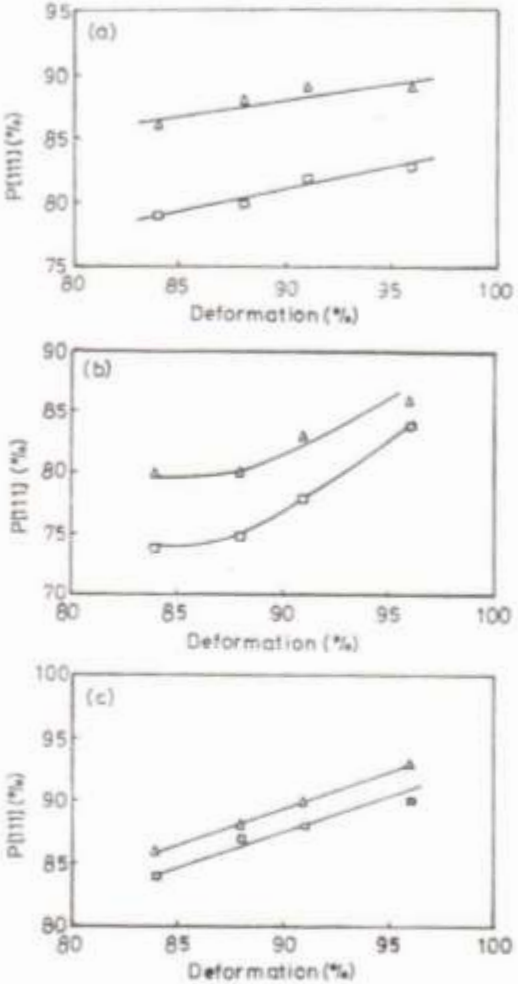

Fig. (3): Relation between elastic modulus and crystallographic texture: (a) Cu, (b) Ag and (c) Al (Δ with □ and without preannealing)

It is worth to mention that, the data (Young's modulus, E) for the samples with and without pre-annealing lie on the same curve, i.e. samples with the same texture have the same values of E whether they were preannealed before cold drawing or not. These results indicate that the values of elastic modulus depend essentially on the type and degree of the crystallographic textue of the wires more than any other macrostrctural characteristics such as grain size. Khidr and Ahmed(3) obtained similar results for pure copper wires. They attributed the dependance of Young's modulus on texture more than other factors to

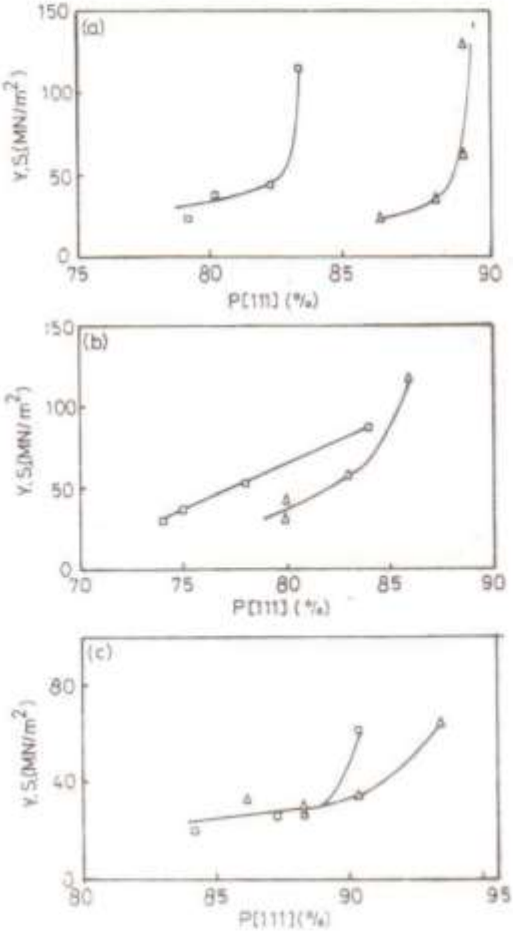

Fig. (4): Relation between yield stress and crystallographic textue: (a) Cu, (b) Ag and (c) Al (Δ with ❑ and without preannealing).

the fact that E is a property of the elastic region. On the other hand, the values of Y.S. and U.T.S. depend, to a degree or another, on other characteristics than the P [111]% as shown in Fig. (3 & 5). This indicates that their dependence on crystallographic orientation is not so much as the elastic modulus, and macrostructure has additional considerable effect, specially in case of yield stress.

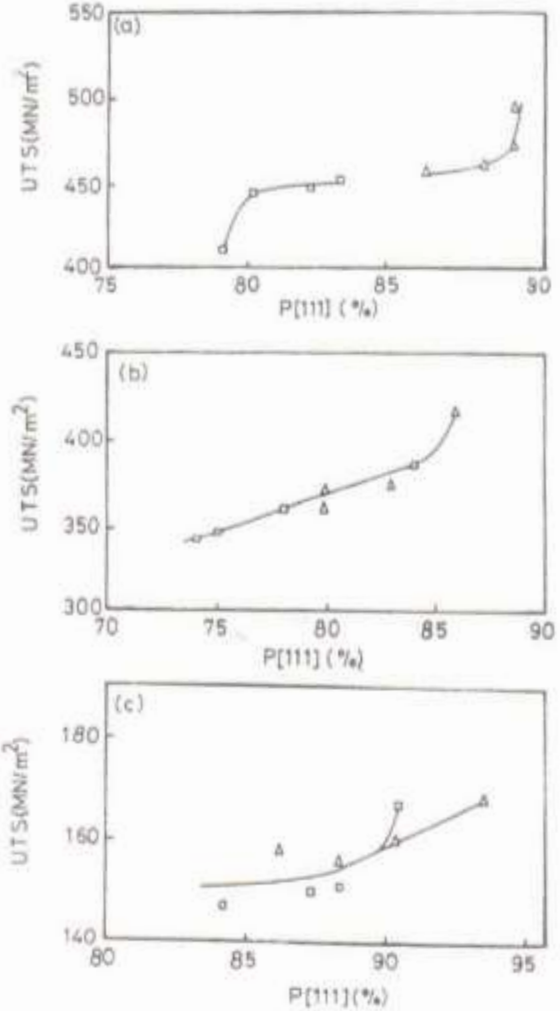

Fig. (5): Relation between ultimate tensile stength and crystallographic texture: (a) Cu, (b) Ag and (c) Al (Δ with and ❑ without preannealing).

(Δ with and ❑ without prennealing)

Conclusion:

It is concluded that the ratio [111] to [100] fiber texture increases for a certain f.c.c. metal as the palstic deformation in one direction (tensile stress) increases. Pre-annealing increases this ratio at any deformation percent. For any specific valaue of plastic deformation, the ratio increases in accordance with the increase of stacking-fault energy. Whatever the history of the wires, pre-annealed or not, Young's modulus depends essintially on the degree of [111] texture. The other mechancial properties (Y.S. and U.T.S.) show less crystallographic orientation-dependence.

Table (1) : Crystallographic preferred orientation data

DEFORMATION (%)	WITHOUT PREANNEALING			WITH PREANNEALING		
	P [111]	P [100]	P [111] %	P [111]	P [100]	P [100] %
			a) Copper			
84	3.08	0.83	79	3.45	0.54	86
88	3.14	0.78	80	3.49	0.47	88
91	3.23	0.73	82	3.53	0.45	89
96	3.29	0.65	83	3.54	0.44	89
			b) Silver			
84	3.03	1.07	74	3.39	0.84	80
88	3.16	1.07	75	3.43	0.87	80
91	3.34	0.97	78	3.63	0.72	83
96	3.67	0.72	84	3.78	0.61	86
			c) Aluminium			
84	3.53	0.68	84	3.70	0.62	86
88	3.76	0.56	87	3.83	0.50	88
91	3.84	0.51	88	3.92	0.43	90
96	3.92	0.45	90	4.10	0.30	93

Table (2) : Mechanical properties of cold drawn wires.

DEFORMATION (%)	WITHOUT PREANNEALING			WITH PREANNEALING		
	E (10^4 MN/m^2)	Y.S. (MN/m^2)	U. T. S. (MN/m^2)	E (10^4 MN/m^2)	Y.S. (MN/m^2)	U. T. S. (MN/m^2)
a) Copper						
84	16.08	24	410	17.41	24	458
88	16.35	38	444	17.52	36	461
91	16.69	44	447	17.71	62	433
96	16.72	115	452	17.78	130	497
b) Silver						
84	8.48	30	342	8.96	31	360
88	8.56	37	347	9.01	42	372
91	8.89	53	360	9.55	58	375
96	9.63	87	389	9.91	118	418
c) Aluminium						
84	7.54	20	147	7.58	33	158
88	7.56	26	150	7.60	30	156
91	7.59	26	151	7.65	34	160
96	7.64	61	167	7.68	64	168

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