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CORRESPONDENCE BETWEEN YOUNG'S MODULUS AND STACKING FAULT ENERGY IN ALPHA BRASSES

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Calculated values of Young's modulus and plastic torsional strain were found to vary with zinc content. They reach maximum value around 1% Zn, then decrease by increasing zinc content. This behaviour was discussed on the basis of accompanied variations in the wire texture and stacking fault energy.

1. Introduction

Wire texture of cold drawn *f. c. c.* metals and alloys have been described as combination of ⟨100⟩ and ⟨111⟩ orientations. The relative amounts of each are variable from one alloy to another, and it has reasonable effect on Young's modulus. The percentage amount of each orientation was related to alloy content, as the texture of copper changes gradually from pure metal type to that of alloy type with increasing alloy content[1]. It is fairly established that the magnitude of the stacking fault energy (*S. F. E.*) controls the dislocation distributions which developed in *f. c. c.* metals during conventional deformation[2]. The present work is an attempt to show correspondence between Young's modulus and stacking fault energy variations in alpha brasses.

2. *Experimental work and results*

Specimens used were in the form of wires 0.5 mm diameter and 10 cm long. The materials were alpha brasses with zinc content 0, 1, 6, 10 and 20 wt pct zinc. Alloys were prepared from high purity copper and zinc in closed graphite mold mechanically agitated for homogenization. The castings were cold drawn to wires 0.5 mm. Precise chemical analysis for the alloy is given in the following table.

TABLE 1

Brass	Copper	Zinc	Iron	Lead	Phosphorus
Pure copper	99.997	0.000	0.001	0.001	0.001
Cu-1% Zn	98.993	1.003	0.002	0.001	0.001
Cu-6% Zn	93.994	6.002	0.002	0.001	0.001
Cu-10% Zn	89.992	10.005	0.001	0.001	0.001
Cu-20% Zn	79.991	20.005	0.002	0.001	0.001

Wires of length 10 cm were taken from each alloy and annealed at 200 °C for different times to get specimens of nearly same grain diameter (0.003 mm) in the recovery stage. From stress strain curves Young's modulus for each alloy was calculated. The variation of Young's modulus with zinc content is shown in Fig. 1 in which it is clear that Young's modulus increase from 12×10^{10} N/m^2 for pure copper to 22×10^{10} N/m^2 for Cu-1% Zn, then it is decreased with further increasing zinc content.

The torsion plastic strain for investigated wires was measured using conventional type twisting machine whose specifications were described elsewhere[3]. Degree of torsional deformation is given by the dimensionless quantity ND/L where N is the number of turns twist, D, L are the diameter and initial length of wire, respectively. Axial tensile stresses of 1, 2, 3, and 4×10^7 N/m^2 were studied by loading the investigated wires with different corresponding loads. Elongation resulted in the wires during twisting was measured by travelling microscope accurate to 1×10^{-2} mm. The strain resulted in wires of different zinc content at different axial tensile stresses are given in Fig. 2 which show that as the axial tensile stresses increased the tensile strain accompanying torsional deformation is increased too. The value of tensile strain per unit torsional deformation at constant tensile stress (s), i. e.

$$\left[\frac{\Delta(\Delta L/L)}{\Delta(ND/L)}\right]_s = \left[\frac{\Delta\varepsilon}{\Delta\Theta}\right]_s$$

could be calculated from the slopes of results in Fig. 2. Fig. 3 shows the effect of zinc content on $\left[\frac{\Delta\varepsilon}{\Delta\Theta}\right]_s$ from which it is clear that $\left[\frac{\Delta\varepsilon}{\Delta\Theta}\right]_s$ increases with raising zinc content to 1%, then it decreased by more raising zinc content. Also it is clear that for all alloys tested increase in axial tensile stress is accompanyied by increase in the value of $\left[\frac{\Delta\varepsilon}{\Delta\Theta}\right]_s$.

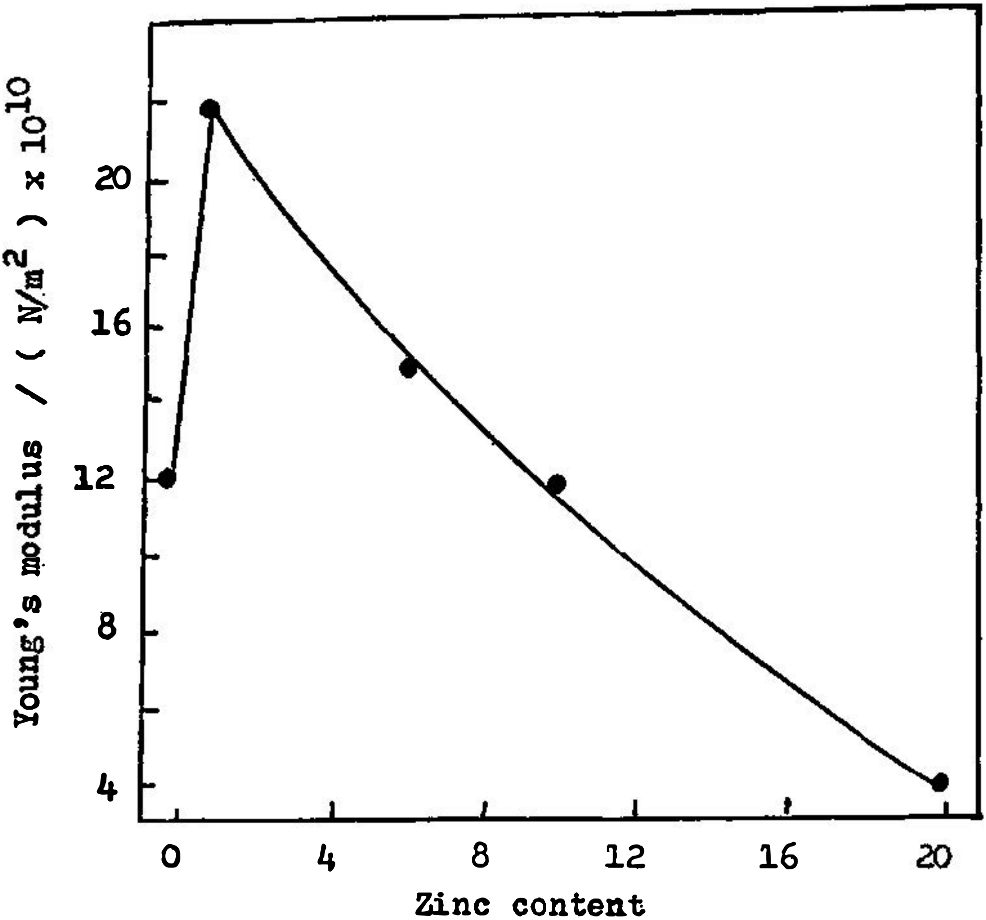

Fig. 1. Variation of Young's modulus with zinc content.

3. *Discussion*

It was assumed that *f. c. c.* metals contain after deformation network of dislocations. These allow the operation of Frank-Read sources to create number of dislocations necessary for plastic flow. Under elastic stress these dislocations bend out between their fixed end points in a reversible way. This elastic motion determines the value of Young's modulus. In alpha brasses dislocations in these networks were locked by solute zinc atoms. For large enough concentration of zinc solute atoms the dislocation line meets zinc atoms on the average at distances which decrease when concentration of zinc atoms increase. Under elastic stress, elastic oscillation of dislocation segments pinned by zinc atoms will take place.

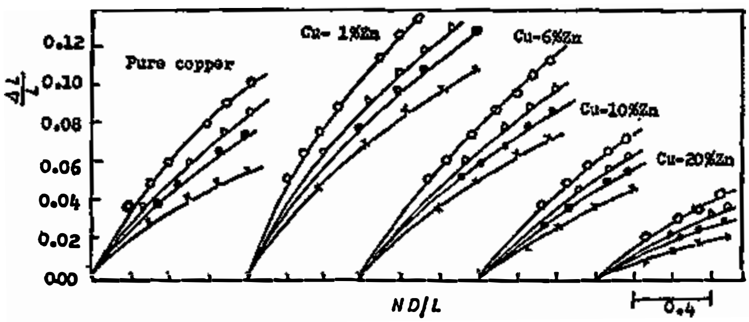

Fig. 2. Effect of varying zinc content on the tensile strain associated with torsional deformation under the axial tensile stresses

1×10^7 N/m² -×-×-×-×- 2×10^7 N/m² -●-●-●-●-
3×10^7 N/m² -Δ-Δ-Δ-Δ- 4×10^7 N/m² -o-o-o-o-

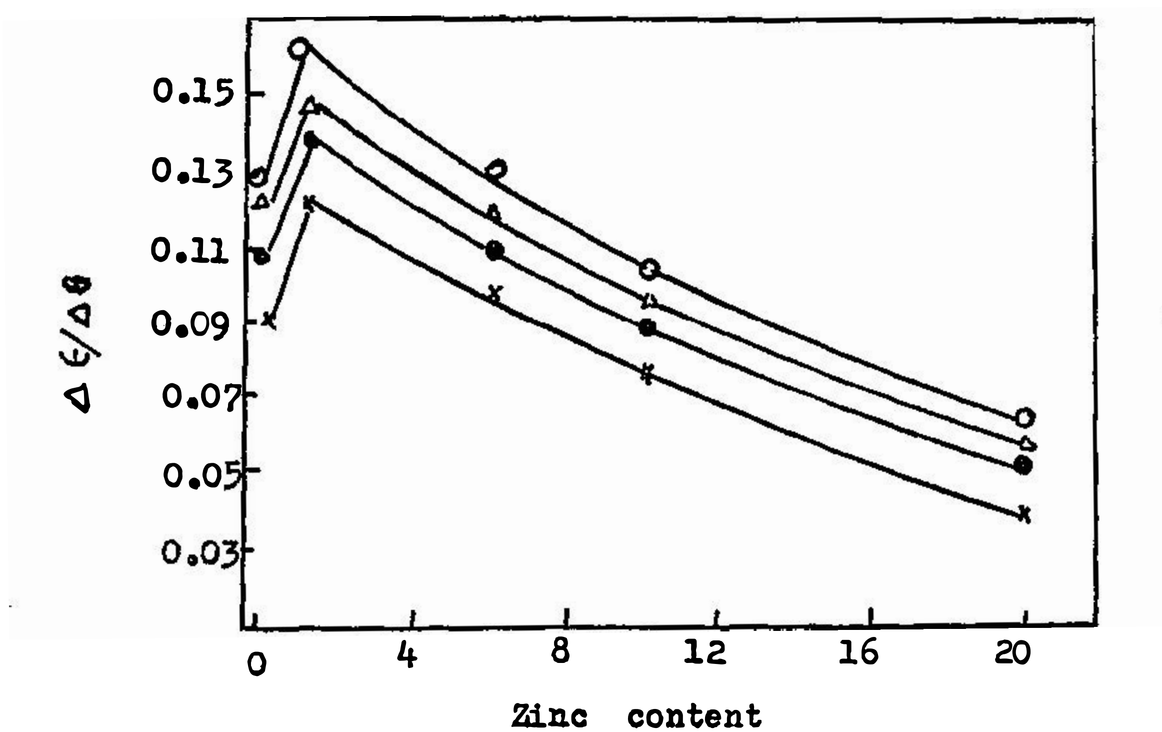

Fig. 3. Dependence of the slope ($\Delta\varepsilon/\Delta\Theta$) on zinc content for the axial tensile stresses

1×10^7 N/m² -×-×-×-×- 2×10^7 N/m² -●-●-●-●-
3×10^7 N/m² -Δ-Δ-Δ-Δ- 4×10^7 N/m² -o-o-o-o-

This discusses the observed reduction of Young's modulus with increasing zinc concentration. Also when the dislocations are extended as in case of alpha brasses there will be additional reduction in the elastic modulus because applied stress changes the width of stacking faults present[4]. At low concentrations of zinc atoms (up to 1% Zn) the modulus variation deviates from its normal assembly and present negative anomaly (increase in Young's modulus) because at this zinc content range acting stress leads to rearrangement of existing dislocations[5] and annihilation of these dislocations by cross slip will in turn increase Young's modulus.

Another reason for the observed variation of Young's modulus with zinc content is the variation of percental existing amounts of ⟨111⟩ and ⟨100⟩ orientation and the accompanying change of texture components with increasing contents. The results given in Fig. 1 indicate that ⟨111⟩ orientation is maximum in alloys of 1% Zn and decreasing ⟨111⟩ orientation texture with increasing zinc content. This trend is in reasonable agreement with previously determined[6] computation of the percental amounts of ⟨111⟩ orientation and given in Table 2.

TABLE 2

Alloy	Pure copper	Cu-1% Zn	Cu-6% Zn	Cu-10% Zn	Cu-20% Zn
$P\langle 111\rangle$ (%)	78	89	87	84	—
$S. F. E.$ (J/m²) × 10^{-3}	77	101	98	81	41

The pronounced behaviour of the combined tensile torsion deformation is that the increase in the applied axial tensile stress is accompanied by an increase in the tensile strain per unit torsion. This shows that a stress dependent process causing an increase in the strain coefficient is taking place during deformation. Because twisting facilitates cross slip[7], and since the activation energy of cross slip decreases by increasing the applied stress[8], it is expected that the application of tensile stress during torsion increases the probability of cross slip mechanism. This cross slip mechanism is that which allows dislocations to move large distances leading to the observed increase in the tensile strain per unit torsion. The results shown in Fig. 3 show that slip distance is maximum in Cu-1% Zn alloy and decreases by adding more zinc atoms. This behaviour might be because in the zinc content up to 1% the added zinc atoms facilitate cross slip by rearrangement of dislocations then added zinc atoms hinder and retard the cross slip mechanism. It is well known that variation of cross slip with added zinc in alpha brasses depend on variation of stacking fault energy. This *S. F. E.* variation which is prototype to results of Fig. 3 agree with previously calculated values[9] for *S. F. E.* in alpha brasses and are given in Table 2 in which Cu-1% Zn alloy has the highest *S. F. E.*

As a conclusion from this study a comparison between effect of zinc content on both Young's modulus and *S. F. E.* show that there is a correspondence between them and that *S. F. E.* could be taken as a criterion for texture transition and Young's modulus variation in alpha brasses.

References

1) H. Wawra, J. Phys. Soc. Japan **23** (1967) 856;

2) T. H. Youssef, Phys. Stat. Solidi (a) **3** (1970) 801;

3) T. H. Youssef and G. Saad, Phil. Mag. A **42** (1980) 217;
4) P. Jongenburger, Acta Met. **11** (1963) 992;
5) M. Koiwa and R. R. Hastiguti, Trans. Japan Inst. Metals **61** (1967) 73;
6) G. C. Kuezynski, Nature **165** (1950) 562;
7) D. B. Holt, Acta Met. **7** (1959) 446;
8) J. Friedel, *Dislocations*, (Pergamon Press), (1964) p. 261;
9) R. E. Smallman and D. Green, Acta Met. **12** (1964) **145**.

POVEZANOST YOUNGOVOG MODULA I ENERGIJE POGREŠAKA U SLAGANJU ALFA MJEDI

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Utvrđeno je da se u alfa mjedi vrijednosti Youngovog modula i torzione deformacije mijenjaju u ovisnosti o sadržaju cinka. Obje vrijednosti postižu maksimum pri 1% Zn, a zatim se smanjuju kako sadržaj cinka raste. U članku se razmatraju te pojave i povezuju se s promjenama teksture žice i energijom pogrešaka u slaganju.