Analysis of Deformation Twin and Mechanical Strength Using Simulation Model in the Deformation Microstructure of Copper Alloy

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ABSTRACT Recently, the compatibility of the strength, the workability, and the high conductivity are needed in copper alloy materials which are produced by controlling the combined process of the cold working and the aging treatment, in response to size reduction of electronic connectors and increase of the assembly density, and in improving the performance of electronic devices. Especially, in the solution hardening alloys, the microstructure change in cold working process becomes a very important factor, although the microstructure change behavior is extremely complex. In this report, the calculation model to evaluate the microstructure changes resulting from the introduction of dislocation, the creation of dislocation cell/substructure and the deformation twin, and the effect of the dynamic recovery in deformation processing, was proposed. And the microstructure change due to cold working processing was analyzed with this model regarding a relationship between a processing condition, the microstructure, and the flow stress. By applying evaluations to various Cu-Zn-Si system alloys which have different stacking fault energy, the validity of the calculation model was confirmed by comparing the experimental and the calculated results. And the concept of the microstructure control in the deformation twin creation based on results of this model calculation was summarized.

1. INTRODUCTION

Recently, along with the higher performance of electronics devices, size reduction of connectors and increase of the assembly density are in progress. Based on the structure controlling of the Copper alloy through a sophisticated combination of the cold working and the aging treatment, a high conductive material, which has both a strength and a workability required as a practical material, have been manufactured. Especially, in the solution hardening alloys, the structure change in the cold working processing becomes a very important factor in controlling its property. Since the phenomenon is very complex, a modeling of the phenomenon and a calculation model based on it are required to control the alloy structure. Therefore, for the purpose of this report, we constructed a model taking into account the dislocation introduction on the structure change due to the processing distortion introduction, the creation of the dislocation cell/subgrain structure, the effect of the deformation twin creation and the dynamic recovery effect. In addition to analyzing a relationship between the processing condition, the structure state and the flow stress, we compared and verified the experimental results and the calculation results for Cu-Zn-Si system alloys whose stacking fault energy, which greatly affects the deformation twin creation, can be controlled by the alloy composition. And, based on the results, in addition to examining the validity of the model, based on the results obtained from the model calculation, the concept of the structure control on the work hardening alloy was summarized.

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2. ANALYSIS METHOD AND PROCEDURE

2.1 Analysis Model for Working Structure Simulation

Figure 1 shows a typical manufacturing process of the Copper alloy and it schematically illustrates the microstructure change during the cold rolling of the Copper alloy. According to the report by Paul et al.[1], a large difference in the microstructure creation state is caused between the case where the refinement of the dislocation cell progresses in the crystal grains and the case where the deformation twin is preferentially formed.

Based on this microstructural change, the structure simulation model in the working process of the Copper alloy was studied.

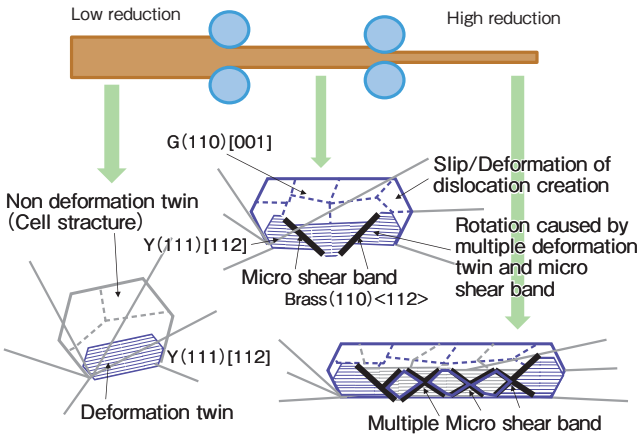

Figure 1 Schematic illustration of microstructure change during cold rolling in copper alloy.

2.1.1 Definitions of the conditions to form the deformation twin during working treatment

Based on the deformation twin creation, the structure change in the working process is considered to occur as follows. As shown in Figure 2, a flow stress competition occurs between the stress $\tau cell$ for creating the substructure such as the dislocation cells and a creation stress $\tau twin$ of the deformation twin, and a deformation occurs in a mode that results in a lower flow stress. It means that, the deformation twin is formed when $\tau cell > \tau twin$. Therefore, It is considered that only when the condition of $\tau cell > \tau twin$ is satisfied in the deformation process, the deformation twin is generated, and the conditions for a pre-creation stage of a multi-micro shear band structure is completed.

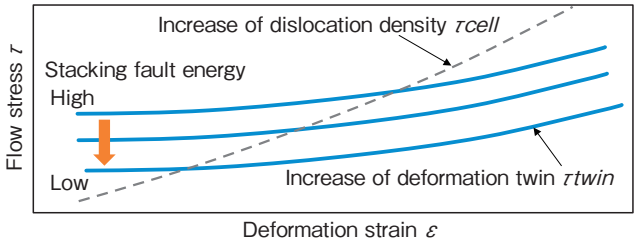

Figure 2 Schematic illustration about the effect of stacking fault energy on flow stress in Copper alloy during cold deformation.

2.1.2 Relation equation between the strain mode and the shear deformation amount

Equation (1) is obtained by defining the slip deformation due to the dislocation cell creation and the deformation due to the deformation twin with the shear deformation amount $d\gamma$.

$$d\gamma=(1-F)d\gamma_g+\gamma_t dF \quad (1)$$

Here, F is the deformation twin fraction, γ_g is the shear strain due to the slip, γ_t is the twin shear strain.[2] In Equation (1), the important thing is the criteria for the generation and growth of the deformation twin caused by the shear deformation. As previously defined, the condition of $\tau cell > \tau twin$, that is, the magnitude of $\tau cell/\tau twin$ directly affects the change for the strain ε of the deformation twin fraction, then it can be shown in Equation (2).

$$dF=(1-F)m\cdot d\varepsilon \quad (2)$$

Here, m is defined as, $m=n_{k1}\log(\tau cell/\tau twin)$.

n_{k1} is a variable related to a nucleation frequency of the deformation twin, and since a grain boundary density is equivalent to a nucleation site density per unit area, there is an effect of proportionality to $1/D$, also there is an effect that the larger the restrained shear force $\delta\tau r$ between the crystal grains the more suppressed the deformation twin creation[3]. And there is a relationship proportional to the 1/2 power of the crystal grain size D as the reciprocal ($1/\delta\tau r$). Based on these n_{k1} can be considered to be a coefficient proportional to $D^{-1/2}$ depending on the product. Therefore, the creation of the deformation twin is a model depending on the crystal grain size before the working treatment.

Also, a creation stress of the dislocation cell depends on the initial gran size and the dislocation density, and the creation stress of the deformation twin is the sum of the creation stress of the extended dislocation and the creation stress of the stacking fault, then these stresses are defined by Equation (3) and Equation (4)[4].

$$\tau cell=2A\mu b/\delta+\alpha\mu b\rho^{1/2} \quad (3)$$
$$\tau twin=2A\mu b_1/\delta+E_{sf}/b_1/n \quad (4)$$

Here, E_{sf} is the stacking fault energy, A and α are constants both 1.0. μ is the shear elastic modulus, ρ is the dislocation density, b is Vurgers vector, b_1 is the partial dislocation Vurgers vector, n is the stacking fault stress concentration factor (n=0.2), and δ is the cell size in the region where twins are not formed.

2.1.3 Relationship between the shear strain amount and the change in the dislocation structure

The dislocation density change in the deformation twin is defined by Equation (5)[2].

$$d\rho/d\gamma=1/(b\cdot\Lambda_1)-f\cdot\rho \quad (5)$$

Λ_1 is $1/D+1/t+k\sqrt{\rho}$, D is the crystal grain size, t is the deformation twin distance and k is a constant (=0.1).

On the other hand, the dislocation density change in the matrix is defined by Equation (6).

$$d\rho/d\gamma=1/(b\cdot\Lambda)-f\cdot\rho \quad (6)$$

Here, Λ is $1/D+k\sqrt{\rho}$, f is a fitting term (dynamic recovery parameter) taking into account an effect that shows decrease in the dislocation density due to the dynamic recovery effect, and is greatly affected by the working condition. The following definition was made in consideration of Zener-Hollmon factor based on the effect of the working strain rate and the working temperature.

$$f=P_{fr}/\log(E_D\cdot R_{sf}\cdot\exp(E/R\cdot(1/T_w)) \quad (7)$$

Here, P_{fr}, R_{sf} are fitting constants, E_D is the strain rate, E

is the diffusion activation energy of the copper, R is the gas constant and T_w is the working temperature.

2.1.4 Relationship between the shear strain amount γ and the structure change in the cell structure

Since the dislocation cell creation rate also changes depending on the dislocation density, these considerations are defined as in Equation (8), using the model proposed by Nes et al.[5].

The change in the cell size per the shear strain is determined by the balance between the size change $d\delta^-/d\gamma$ due to the strain and the coarsening of the cell $d\delta^+/d\gamma$ due to the dynamic recovery.

$$d\delta/d\gamma=d\delta^+/d\gamma+d\delta^-/d\gamma \quad (8)$$

Applying the relationship of Equation (8) to the change in the cell size within the deformation twin,

$$d\delta^+/d\gamma=V_d\cdot b^2\cdot B_g\sqrt{\rho}\cdot\{\exp(-(U_{sd}-PV_a)/(kT_w))\} \quad (9a)$$
$$d\delta^-/d\gamma=-\sqrt{3}b^{1/2}\cdot\delta^{5/2}/(\phi^{3/2}\cdot\delta_{ini}\cdot K_{iv}) \quad (9b)$$

δ_{ini} is the initial dislocation cell size, T_w is the working temperature, U_{sd}, P, V_a are values related to the dynamic recovery activation energy of the dislocation.

On the other hand, applying the relationship of Equation (8) to the change in the dislocation cell size within the matrix,

$$d\delta^+/d\gamma=V_d\cdot b^2\cdot B_g\sqrt{\rho}\cdot\{\exp(-(U_{sd}-PV_a)/(kT))\} \quad (10a)$$
$$d\delta^-/d\gamma=-\sqrt{3}b^{1/2}\cdot\delta^{5/2}/(\phi^{3/2}\cdot\delta_{ini}\cdot K_{iv}) \quad (10b)$$

This δ_{ini} is limited to the deformation twin distance, then the cell refinement is easy to be caused by the initial stage of the deformation. Here, the values used by Nes et al.5) were used to the model calculation from Equation (9a) to Equation (10b).

2.1.5 Relationship between the creation limit of the deformation twin and the micro shear band

As shown in Figure 1, as the working treatment proceeds, as the refinement proceeds in the dislocation cell within the deformation twin, and the micro shear band crossing the deformation twin is formed. This phenomenon is considered to be caused by the change of the deformation mode, since the dislocation cell within the deformation twin is getting closer to the refinement limit.

Though, there is no clear report about the critical value of the dislocation cell size within the deformation twin, it is considered that the value is close to 10 nm which is equivalent to the crystal grain refinement limit δ_{crit} .

Therefore, considering that due to the strain ε_{sb} , which is generated by the creation of the micro shear band, the deformation strain by the deformation twin creation is reduced by ε_{sb} , the equation of the generation and the growth shown in Equation (2) can be rewritten as follow.

$$dF=(1-F)m\cdot d(\varepsilon-\varepsilon_{sb}) \quad (2b)$$

By expressing the ratio $R_{sb}(=\varepsilon_{sb}/\varepsilon)$ which is the ration between the deformation twin creation related strain ε and the micro shear band creation related strain ε_{sb}, it can be explained as in Equation (11) in the three dimensional structure model of the expand volume theory, by using the dislocation cell sizeδ_{twin} within the deformation twin and the critical value δ_{crit}(=10 nm).

$$R_{sb}=1-\exp\{k_{twin}\cdot(\delta_{crit}/\delta_{twin})^3\} \quad (11)$$

Here, k_{twin} is the fitting parameter and by using the above Equation, it is available to calculate and evaluate the creation progress state of the deformation twin in consideration of the micro shear band creation.

2.1.6 Relationship between the structure parameter and the flow stress/proof stress

From the above shown relationship, the flow stress in the dislocation cell structure region and the flow stress in the deformation twin creation region can be obtained from the Equation (12)[6].

$$\sigma_w=\sigma_0+K_1\rho^{1/2}+K^2\delta^{-1}+K^3d_{twin}^{-1/2} \quad (12)$$

Here, σ_0 is the yield stress of the single crystal, ρ is the dislocation density, δ is the dislocation cell size, d_{twin} is the deformation twin distance, K_n(n=1~3) is a parameter depending on the Taylor factor. When the share of stress in the non-deformation twin region is σ_w(M), and the share of stress in the deformation twin region is σ_w(T), the flow stress σ_{wf} in the working process of the entire structure is shown in Equation (13).

$$\sigma_{wf}=(1-F)\cdot\sigma_w(M)+F\cdot\sigma_w(T) \quad (13)$$

2.1.7 Calculation procedure using the working structure simulation model

The calculation procedure in this simulation model is as follow.

At first, obtain each flow stress of the matrix and of the deformation twin region in the case of the unit shear strain is applied, from the calculation results of the dislocation density and the cell size taking into account the dynamic recovery effect. And based on this, the deformation twin creation state corresponding to the working strain is calculated.

The next procedure is to calculate the strength property (the flow stress) from the obtained structure parameter value.

On proceeding with the calculation, in order to determine the deformation twin creation stress, the stacking fault energy, the working condition and the initial structure are very important influencing factors.

Then, the values were verified using literature values from Ab-initio calculation[7], and the correspondence between the calculation results and the alloy compositions were examined.

In addition, regarding the effect of the working condition and the initial structure, the evaluation was proceeding under the calculation condition that enables the comparison with the prototype evaluation results on Cu-Zn-Si system alloys.

2.1.8 Experimental structural property evaluation with the Copper alloy

The Copper alloy, with 5 to 30 mass% of Zn and 0.03 to

0.5 mass% of Si, was melted, casted and hot-rolled and the thickness was adjusted to 2.5 mm by cold- rolling. Then it was heated for 2 hours and air cooled at 380°C and the roll-working treatment was applied within the range of 1.6 to 2.5 of strain. After these treatment, the Copper alloy was evaluated on 0.2% proof stress by the tensile test, on the structure analysis by X-ray diffraction (XRD) with a {111} diffraction intensity/total peak intensity, and on the lamella distance of the deformation twin by a transmission electron microscope.

In addition, the deformation twin fraction was calculated by normalization of the {111} diffraction intensity ratio/total peak ratio through the powder method. Further, in order to investigate the influence of the working temperature, the materials were kept at room temperature and at liquid nitrogen temperature were rolled, and the similar evaluations were performed.

3. RESULTS

3.1 Calculated Alloy Composition

As the alloy evaluation data, used to examine the correspondence with the simulation calculation values, a comparison was made with the alloys having compositions shown in Table 1.

Table 1 Alloy compositions used for experimental evaluation, model calculation and stacking fault energy evaluated from Ab-initio calculation[7] based on alloy compositions.

Alloy symbol	Zn (mass%)	Si (mass%)	Stacking fault energy (J/m^2)
30Zn0.03Si	30.2	0.031	0.015
30Zn0.5Si	32.5	0.45	0.013
5Zn0.03Si	5.1	0.021	0.034
5Zn0.5Si	5.0	0.39	0.030

3.2 Numerical Study on the Simulation Parameters

The stacking fault energy was reported to be 0.055 J/m^2 for 5%Zn alloy and 0.014 J/m^2 for 30%Zn alloy, and according to the evaluation by Ab-initio cluster variational calculation[7] , 0.03 J/m^2 for 5%Zn-0.5%Si alloy and 0.010-0.014 J/m^2 for 30%Zn-0.5%Si alloy. In this calculation, the values shown in Table 1 were used. As shown in Figure 3, regarding the effect of the initial crystal grain size D on the deformation twin distance t, specimen materials were processed in different sizes for Cu30%Zn0.03%Si alloy, and the lamella distance of twin was measured using the transmission electron microscope. Then, the relationship of Equation (14) was obtained. And this relation was used for the calculation.

$$T=0.0025D+23.0\,[\mathrm{nm}] \qquad (14)$$

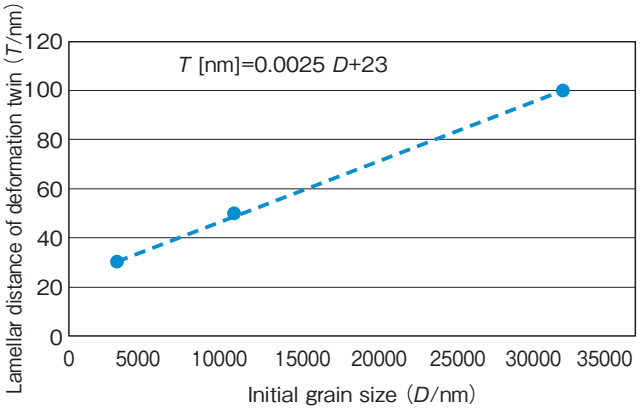

Figure 3 Relationship between the initial grain size and the lamellar distance of deformation twin in Copper-Zinc alloys.

Other simulation parameter values used in this model calculation are shown in Table 2.

Table 2 The values of parameter and constant used in the simulation model.

(1) Calculation of the deformation twin creation		
M_0	Taylor factor	0.3
μ	Shear modulus	48.3×10^9 N/m^2
b	Vurgers vector of the full dislocation	$0.3615/\sqrt{2}$ nm
b_1	Vurgers vector of the partial dislocation	$0.3615/\sqrt{6}$ nm
n_{k1}	Parameter of dependency in grain size	$5.6\times10^{-4}\cdot D^{-1/2}$
P_{fr}	Fitting parameter of the dynamic recovery	70
R_{sf}	Fitting parameter of the dynamic recovery	1×10^5
E	Activation energy of the Copper diffusion	70 kJ/mol
(2) Criteria of the Micro shear band creation		
k_{twin}	Fitting parameter in formation of the micro shear band	5
(3) Calculation of the strength property		
K_1	Fitting parameter in the effect of the dislocation	$A\mu bM_0$ (A=1.0)
K_2	Fitting parameter in the effect of the deformation twin	$A_1\mu bM_0$ (A_1=1.0)
K_3	Fitting parameter in the effect of the grain size	$A_2\mu b^{1/2}M_0$ (A_2=0.5)

3.3 Comparison Between the Model Calculation and the Experimental Results

3.3.1 Calculation results

The calculation results of the work hardening property, the deformation twin fraction and the dislocation cell size within the deformation twin, based on the simulations performed under the condition of room temperature (297 K) and the low strain rate 1/s, are shown in Figure 4, Figure 5 and Figure 6.

As the stacking fault energy decreases, the deformation twin creation starts from the low strain amount region, and the tendency of the work hardening is to occur more easily due to the effect of the accumulation of the dislocation caused within the deformation twin and the cell refinement.

In this model calculation, the increase of the flow stress from the strain was more remarkable as the reduction of stacking fault energy.

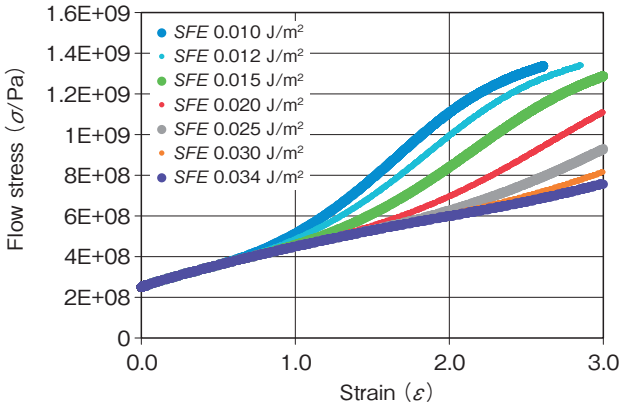

Figure 4 Calculation results of the flow stress-strain curve in various stacking fault energy alloys. (*SFE*: 0.01~0.034 J/m², *D*=10 μm)

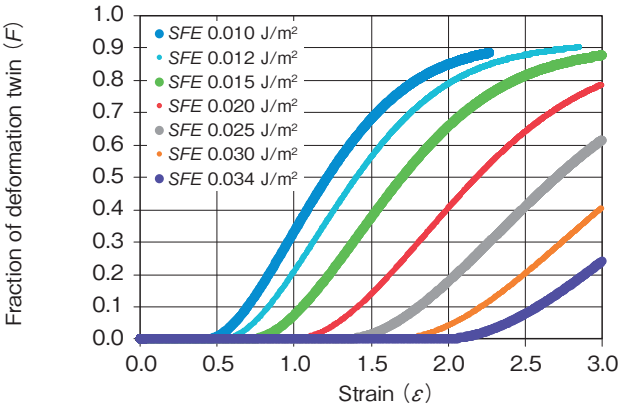

Figure 5 Calculation results of the deformation twin fractionstrain curve in various stacking fault energy alloys. (*SFE*: 0.01~0.034 J/m², *D*=10 μm)

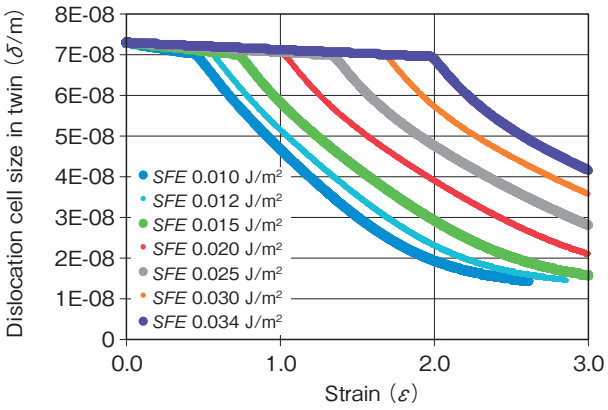

Figure 6 Calculation results in the change of dislocation cell size in various stacking fault energy alloys. (*SFE*: 0.01~0.034 J/m², *D*=10 μm)

3.3.2 Effects of the Alloy Composition (Stacking Fault Energy) and the Initial Structure

Figure 7 shows the relation between the flow stress at the plastic strain ε=1.6 obtained from the calculation and the 0.2% proof stress of the specimen experimentally processed at the plastic strain ε=1.6, also shows the correspondence between the calculated and the experimental values of the deformation twin fraction. Here, those having the multiple data in the same alloy system, including the data at different initial grain sizes and working temperatures. It can be seen that the experimental proof stress corresponds well to the calculated value. And, the value on the deformation twin fraction obtained by the structure analysis on the processed sample has relatively good correspondence with the calculated value. At a strain amount of 1.6, due to the difference in the stacking fault energy, 400 MPa or more of strength difference was caused, this is considered to be extreme.

For a Cu30%Zn0.05%Si alloy with a composition equivalent to 0.015 J/m² of the stacking fault energy, under the condition of different initial crystal grain sizes, the strain amount dependence of the deformation twin in the creation state was compared between the experimental values and the calculated values as shown in Figure 8.

And it was confirmed that as the grain size increases the amount of strain, which accelerate the deformation twin, increases. With this model, it is considered that the evaluation of the contribution to the creation process and the strength of the deformation twin are possible. Figure 9 shows the relationship between the calculated flow stress and the one experimentally obtained 0.2% proof stress. It can be seen that even with the working strain amount of 1.6, a strength difference of approximately 100 MPa occurs due to the difference in the initial crystal grain size.

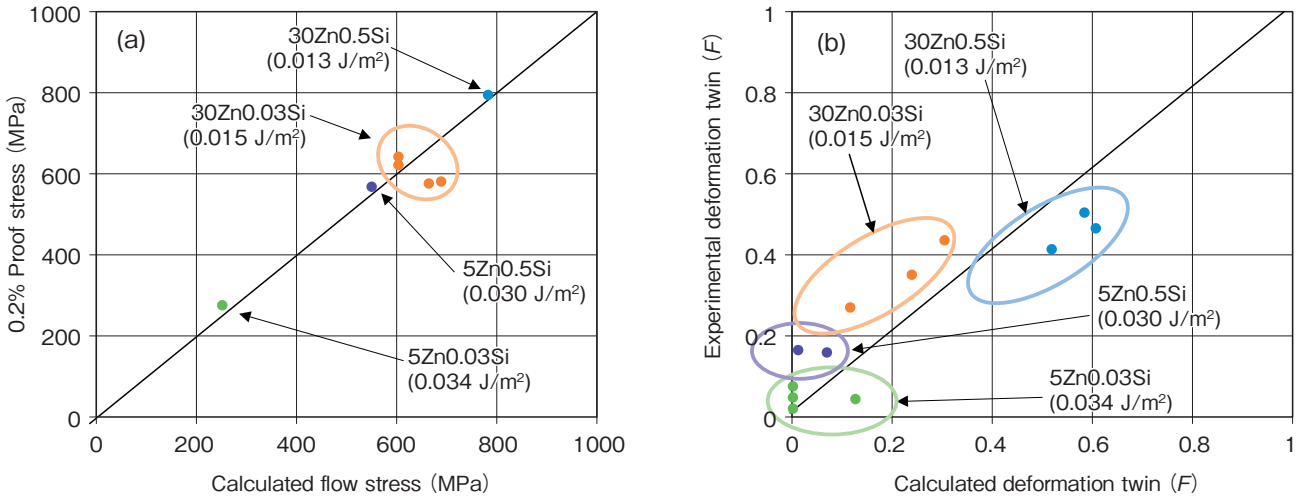

Figure 7 Relationship between calculated and experimental results in (a) the strength property and (b) the fraction of deformation twin at the condition of strain ε=1.6.

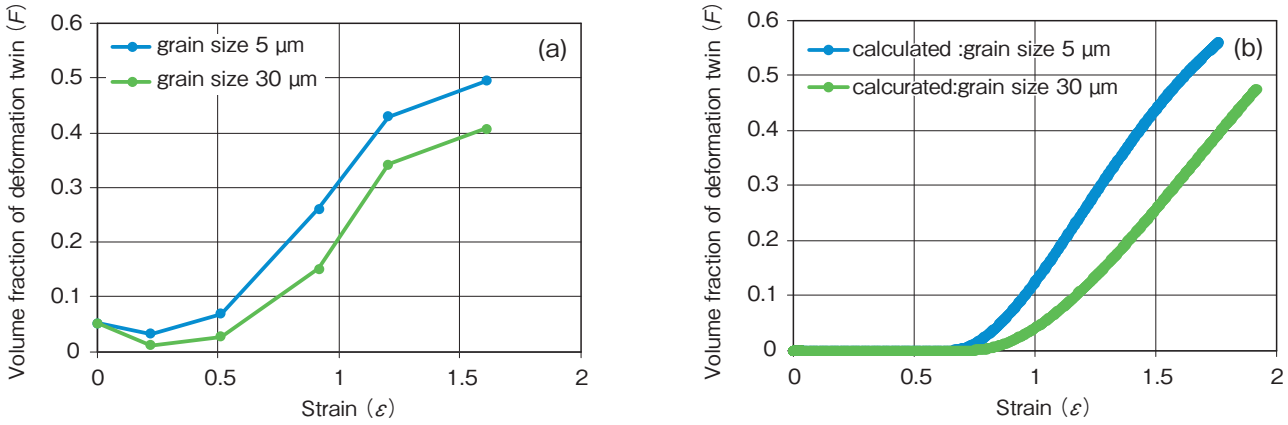

Figure 8 Fraction of deformation twin-strain curve in (a) the experimental evaluation and (b) the model calculation at the condition of stacking fault energy: 0.015 J/m^2 in Cu30%Zn0.03%Si alloy.

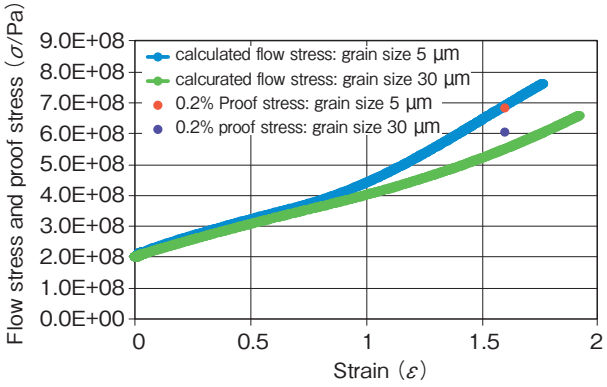

Figure 9 Calculated Stress-strain curve and 0.2% proof stress evaluated experimentally at deformation strain ε=1.6 in Cu30%Zn0.03%Si alloy. (*SFE*: 0.013 J/m^2)

Figure 10 shows the evaluation result of the effect on the creation process of the deformation twin when the initial crystal grain size of Cu30%Zn0.5%Si alloy is changed more. It can be confirmed both from the experimental results and the calculation results, that the effect of the suppression on the creation of the deformation twin is expressed. However, regarding the dependence of the deformation twin creation process on the initial crystal grain size, since there are some difference in correspondence relation between the experimental values and the calculated values, for more detailed analysis , it is necessary to consider not only the initial crystal grain size but also the influence of the initial texture.

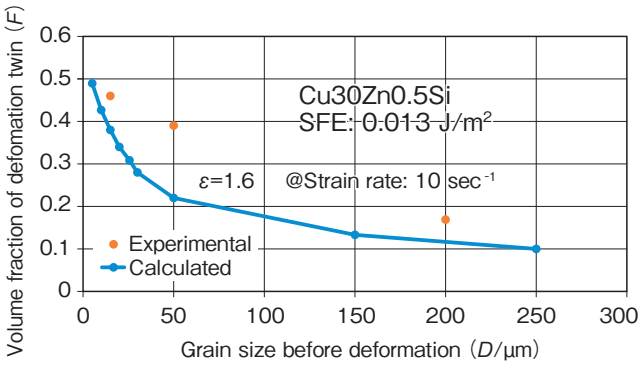

Figure 10 The effect of the grain size before deformation to the volume fraction of deformation twin shown with calculated and experimentally evaluated results at the condition of deformation strain in Cu30%Zn0.5%Si alloy. (*SFE*: 0.013 J/m^2)

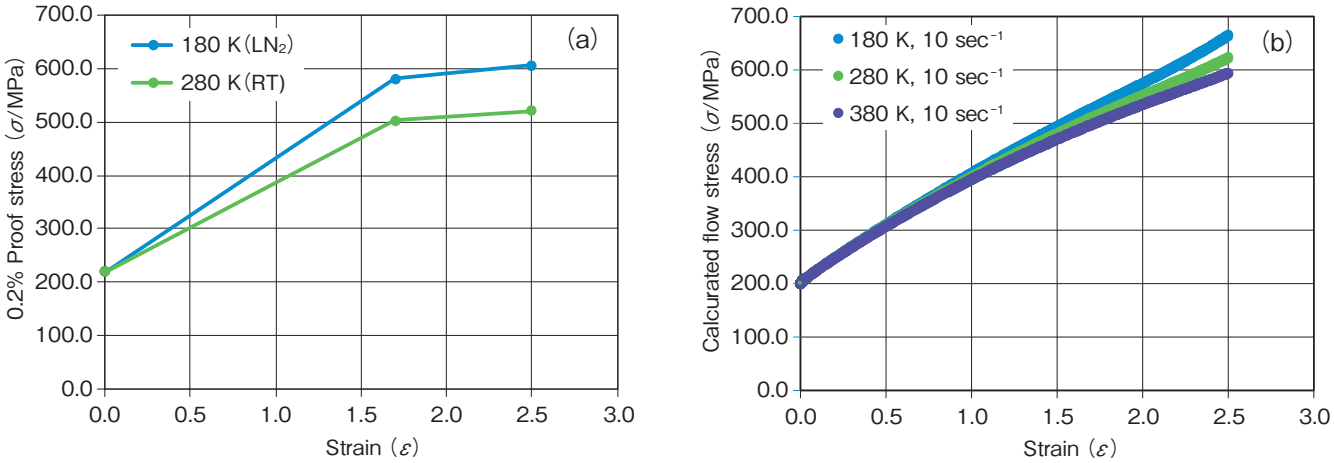

Figure 11 Stress-strain curve in (a) the experimental evaluation and (b) the model calculation at the condition of stacking fault energy 0.034 J/m^2 in various deformation temperature in Cu5%Zn0.03%Si alloy.

3.3.3 Effects of the working condition

Figure 11 shows the correspondence between the experimental values and the calculation values of the work hardening property of the Cu5%Zn0.03%Si alloy with the stacking fault energy of 0.030 J/m^2, one was kept in room temperature another was cooled by the liquid nitrogen (equivalent to 180 K) and were rolled out.

It was experimentally confirmed that the liquid nitrogen cooling rolling has a better work hardening property than the one of the room temperature rolling, and this is corresponding to the calculation values. It is necessary to take into account the effect of the working heat generation on the correspondence between the experimental working temperature and the working temperature of the model calculation, and the verification with higher accuracy will be a future issue. Based on the results obtained for this time, the effect of the working temperature appears as a strength difference of about 60 - 80 MPa at 1.6 strain amount, based on the experimental values and the calculation values.

4. CONSIDERATION

4.1 About the Structure Control Using the Deformation Twin Creation and the Work Hardening Property

Comparing Figure 4, Figure 9 and Figure 11 which show the flow stress change behavior obtained by the calculation, it can clearly be considered that the stacking fault energy, that is, the alloy composition gives the largest influence to the strength change caused by the working treatment. However, on the other hand, the alloy with low stacking fault energy of 0.010 J/m^2 tends to be suppressed by the creation of the deformation twin as shown in Figure 5. Because, when strain amount exceeds 2.0, the dislocation cell size comes closer to the refinement critical value of 10 nm as shown in Figure 6, and the contribution of the strain increases due to the creation of the micro shear band. This indicates that, materials with small stacking fault energy are structurally restricted in a large working strain region of over 2.0 strain amount, and have the possibility to lower the work hardening property. Also, considering by taking the effect of the initial crystal size as an example, the grain size gives large effect on the lamella distance of the deformation twin, and by reducing the initial crystal grain size, the refinement of the dislocation cell size within the deformation twin becomes easier. So, it can be considered that this similarly affects the deformation twin and the creation of the micro shear band.

This fact indicates that the factors of the alloy composition and the initial crystal grain size do not simply affect in a synergistic manner on the strength properties. Then, based on these effects, when the alloy composition and the working initial structure state were used as parameters, we examined how the working structure creation and the changes in the strength properties were affected.

4.2 About the Concept of the Structure Control of the Deformation Twin Forming Alloy

Figure 12 shows the results of the modeling calculation for the consideration of the effects of the stacking fault energy and the initial crystal grain size in the working process on the deformation twin creation also the refinement and the change in the strength of the dislocation cell structure. When the strain is applied to the material with 1 μm and 30 μm of the initial grain size, which has a high stacking fault energy of 0.03 J/m^2, at the strain amount ε of 2.5, the creation of the deformation twin proceeds to about 52% under the condition of the small initial grain size (1 μm). But, under the condition of the large grain size, the creation of the deformation twin proceeds only to about 16%, and it is resulting in that smaller the initial grain size is the higher strength is obtained by the work hardening. On the other hand, when the stacking fault energy is as low as 0.01 J/m^2, by using the material with the small initial crystal grain size of 1 μm in diameter, due to the working strain, the deformation twin creation proceeds from the low strain amount state and the refinement of the dislocation cell proceeds from the low strain working condition, and it is considered that the high

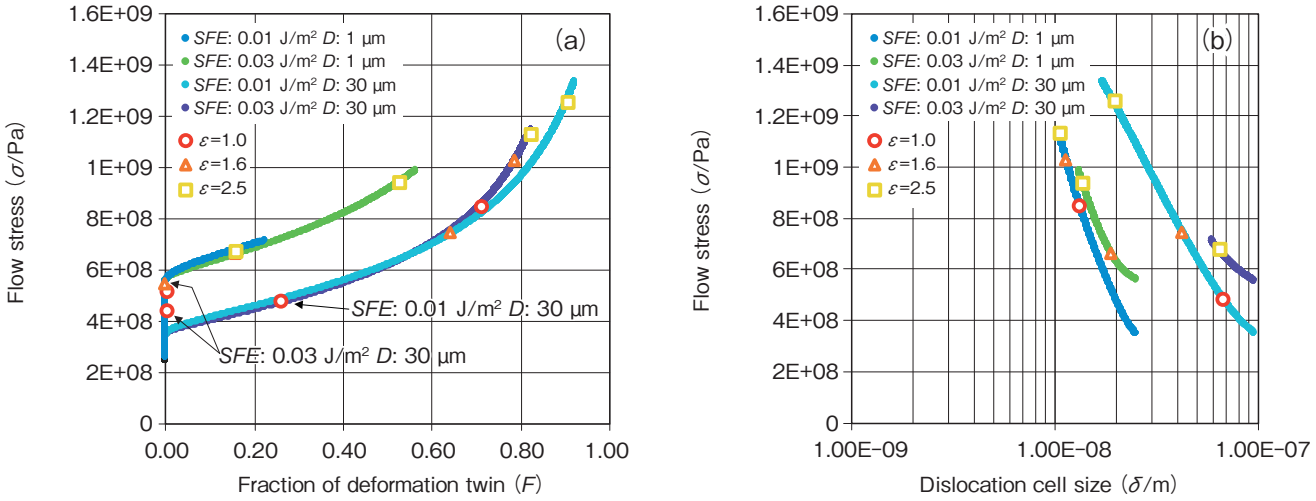

Figure 12 Calculated results of (a) the stress-deformation twin fraction curve and (b) the stress-dislocation cell size at the condition of stacking fault energy: 0.01 J/m^2 and 0.03 J/m^2.

strength properties can be expected in the low strain working state (ε=1.6). Further , on the other hand, in the working treatment of the high strain amount region (ε=2.5), the creation of the micro shear band and its multiplexing occur preferentially, so the change in the strength properties on the strain amount is smaller. Against these trends, it is considered that, in the material with the same stacking fault energy and the large initial crystal grain size (30 μm), even the strain amount, at which the creation of the deformation twin is activated, shifts to a slightly higher side, but due to the effect of widening the lamellar distance of the deformation twin formed by the coarsening of crystal grain, the refinement of the dislocation cell is greatly eased and the creation of the micro shear band also shifts to the high strain amount region. As a result, under the high strain working condition of ε=2.5, since the effect of the initial crystal grain reverses against the deformation twin fraction and the strength, compared with the stage of the strain amount ε=1.6, then the larger initial crystal grain possible lead to the higher work hardening property. As described above, considering the structure change and the strength change due to the working condition, in case of the material with the low sacking fault energy, in the high working stress region, the competition is caused between the creation of the multi-micro shear band and the refinement of the dislocation cell, the occurrence of a specific behavior is suggested and it is considered to be an important factor in the material property designed under the high working strain state. In the future, by applying this model calculation, it is necessary to search for the optimum structure design condition of the work hardening series alloys in consideration of the alloy compositions, the various structure parameters and the working conditions.

5. CONCLUSION

1. The working structure calculation model was developed taking into account the structure state which is determined based on the balance of the flow stress necessary for the refinement of the dislocation cell and the introduction of the deformation twin, also taking into account the strain model in which the working deformation limit, which is created by the dislocation cell refinement limit, is relaxed due to the introduction of the micro shear band.
2. In this calculation model, calculation was performed in consideration of CuSiZn alloy composition, the initial crystal structure and the working condition, and good correlation was obtained as a results of examining the correspondence with the experimental results.
3. By using this calculation model, the influence of various parameters on the working structure creation can be understood, and it was found that important knowledge can be obtained in proceeding the work hardening system alloy composition designing and the process designing.

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