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EVALUATION METHOD OF MICROSTRUCTURE FOR PREDICTION OF AGEING PROGRESS IN HYPO-EUTECTOID CARBON STEEL

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Summary. *The concept of the metal forming analysis is introduced, taking the effect of dynamic ageing into consideration. The new concept is that the ageing in the micro stage and the deformation and the temperature rise in the macro stage should be analysed simultaneously. In this paper, a numerical method for the micro stage is proposed to predict the progress of ageing from the cementite morphology in hypo-eutectoid steel.*

1 INTRODUCTION

Some phenomena of ageing bring advantages in industrial fields. One of the advantages of ageing is that the material can be hardened by heat treatment at low temperature after the material is worked and finished into its final geometry. Because of this advantage, ageing is applied to carbon steels with various ranges of carbon content. For low carbon steel, it is applied to produce bake hardened steel for the outer panels of automobiles[1]. Ageing realises a high tensile strength, geometrical precision and surface quality, because the steel is hardened at low temperature after press forming. For the medium carbon steel, ageing is applied to produce wire rod as a material for cold forging[2]. High drawability is secured during drawing and strain ageing resistance is improved through ageing treatment after drawing. For high carbon steel, strain hardening is applied to produce spring steel.

Besides the case where ageing is applied deliberately, ageing often must occur inevitably. In some metal forming processes, the deformation is high enough to cause the ageing dynamically. The deformed geometry or the hardness may be changed by the dynamic ageing. However, there is little research on the topic.

In the present paper, a concept of the metal forming analysis is introduced, taking the effect of dynamic ageing in the micro stage into consideration. As a first step of this kind of analysis, a numerical method for the micro stage is proposed for the prediction of the ageing progress from the cementite morphology in hypo-eutectoid steel.

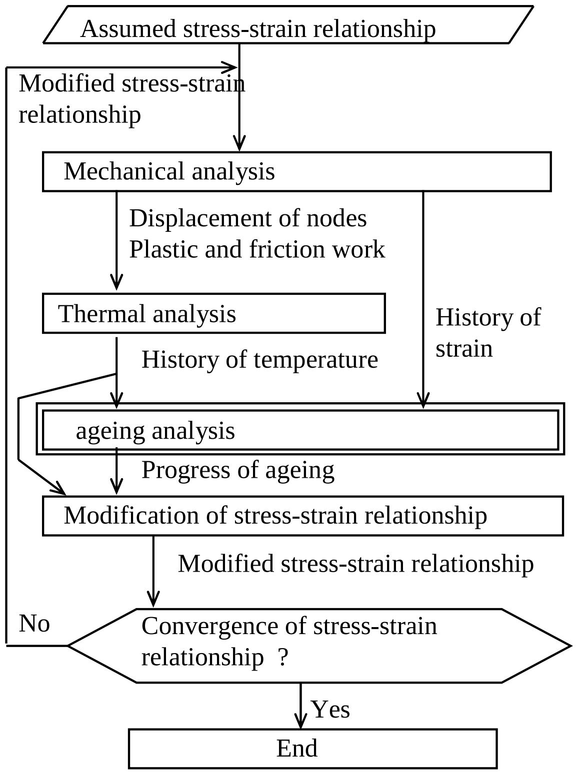


Fig. 1 Concept of metal forming analyses considering ageing

2 CONCEPT OF METAL FORMING ANALYSES CONSIDERING AGEING

The new concept for metal forming analysis is shown in **Fig. 1**. First, a stress-strain relationship is assumed from tension tests in a room temperature. Based on this relationship, the mechanical analysis is carried out, followed by the thermal analysis. Using the analysed history of strain and temperature by the mechanical and thermal analyses, ageing analysis is carried out. The stress-strain relationship is modified according to the ageing progress during deformation. This set of analyses is carried out until the stress-strain relationship converges.

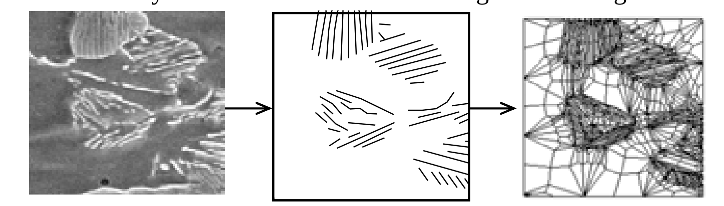


Fig. 2 Modelling of microstructure for ageing analysis

The ageing analysis at the micro stage is carried out similar to the conventional thermal analysis. The FEM mesh is generated based on the microstructure image by optical microscope and a scanning electron microscope (SEM) as shown in Fig. 2.

In a previous research work[3], it was suggested for eutectoid carbon steel that the carbon atoms, which are released during the decomposition of cementite, segregate into the dislocation and raise the hardness of

Black line: Cementite, White part: Ferrite

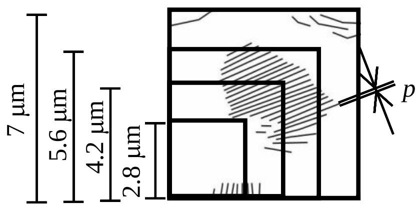


Fig. 3 Modelling parameters

the material. This same mechanism is assumed here.

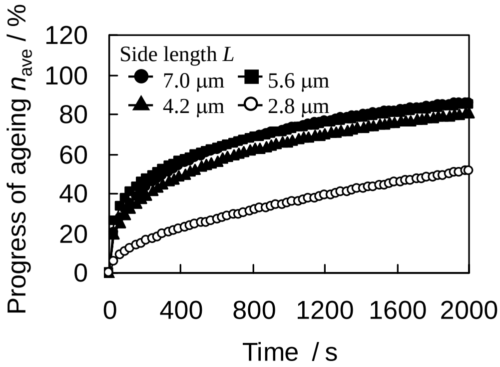
Inside the ferrite region, the carbon is assumed to diffuse employing Fick's second law as follows:

$$dn/dt = D(d^2n/dx^2) \qquad (1)$$

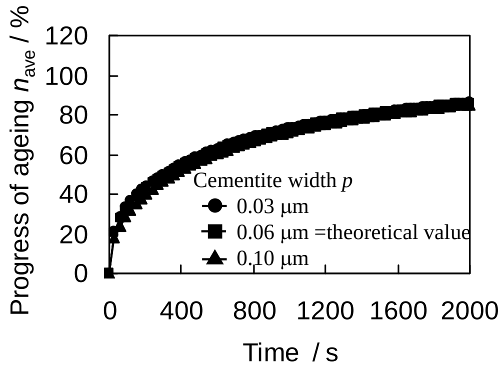
Where, t : time, D: diffusion coefficient,
n: carbon concentration (0.0-1.0:saturated)
x: position

It is also assumed that carbon is decomposed from cementite in proportion with "carbon transfer coefficient α" as follows

$$dn/dt = \alpha(1-n) \qquad (2)$$



(a) Influence of side length of FEM mesh a
(Cementite width p = 0.06 μm)



(b) Influence of Cementite width p
(Side length of FEM mesh a = 7.0 μm)

Fig. 4 Influence of modelling parameters on the analytical results of ageing

3 EVALUATION METHOD OF MICROSTRUCTURE IN AGEING ANALYSIS

There are mainly two problems concerning the modelling of the SEM image as shown in **Fig. 3**. One is the side length of mesh a and the other is the width of cementite p. The larger a, the more precise the prediction, however, more calculation time is required. Although the cementite width p is calculated theoretically from the carbon content, mass number and density, this kind of arrangement may become complex.

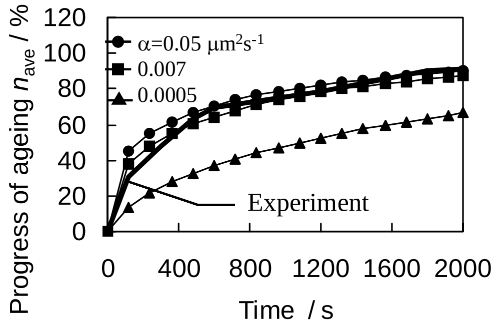
Figure 4 shows the influence of side length L and the cementite width p on the progress of ageing calculated in the micro stage. The progress of ageing n_{ave} is defined as the average value of the carbon concentration n in the area of ferrite. As the side length L becomes large, the calculated results seem to converge to a certain curve. Therefore, this kind of preliminary study is necessary to decide the area for FEM mesh in advance. The side length of 7.0 μm is the minimum necessary for this microstructure in Fig. 3.

As the pearlite width p has small effect on the analytical results, it is not necessary to choose the width p precisely. Because the cementite works as "a radiator" to transmit carbon, it would be important to evaluate the length of cementite precisely instead of the width p.

4 DECISION OF MATERIAL PROPERTY

Using the proposed analysis for the progress of ageing, one of material property, which has not been defined, was decided by comparing the analytical results and the experimental values.

The results are shown in **Fig. 5**. The progress of ageing is defined experimentally as the proportional value to the change of Vicker's hardness. From this results the carbon transfer coefficient from cementite is evaluated as around α=0.007 $\mu m^2 s^{-1}$.

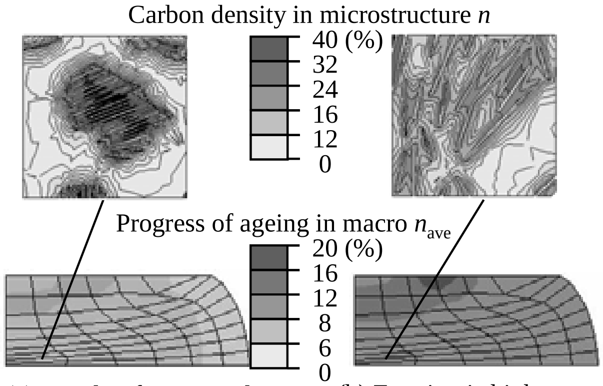


Ageing temperature T_a = 473 K
Diffusion coefficient D = 0.001 μms^{-1}

Fig. 5 Decision of carbon transfer coefficient α

5 EXAMPLE OF METAL FORMING ALANYSIS CONSIDERING AGEING

Employing the new concept shown in Fig. 1, the analysis for axis symmetric upsetting was carried out considering ageing in the macro stage. The commercial code ELFEN, which was developed by Rockfield Software Limited at the University of Wales, Swansea, was used for the analysis in the macro stage. **Figure 6** shows the progress of ageing of different microstructures, observed in actual SEM observations. It is predicted that the progress of ageing differs depending on the microstructure. In other words, it is necessary to consider the microstructure in order to predict the dynamic ageing in the metal forming.



(a) Pearlite fraction is low (b) Fraction is high

Fig. 6 Example of analysis of metal forming considering ageing

6 CONCLUSIONS

(1) The concept of metal forming analyses was introduced, taking the effect of dynamic ageing into consideration.
(2) An evaluating method of microstructure was studied for ageing analysis in the micro stage, that is to say, the preliminary study is necessary to decide the necessary area for FEM mesh and the width of cementite is not an important factor.
(3) The carbon transfer coefficient was decided using the ageing analysis.
(4) Examples of metal forming analysis were shown employing the new concept.

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