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The upper and lower flow curves in a ferrite-martensite steel for multi-purpose use - predictions and experiments -

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We have investigated the upper and lower flow curves which could be obtained depending upon the microstructure without changing chemical composition. The flow curves of multi-structure steels were predicted using the secant method based on micromechanics. The upper and lower curves are estimated to be obtained by exchanging the matrix and inclusion. On the other hand, the microstructure of an Fe-Mn-Si-C system was controlled to be two types of ferrite-martensite ones by heat treatments. Hereby, we can expect a wide range of mechanical properties for multi-purpose use.

1. Introduction

We are investigating a trial of multi-purpose use by microstructure control in an Fe-Mn-Si-C system[1]. It is believed that this alloy system can be used for multi-purpose use and must be used in future from viewpoints of recycling and shortage of natural resources.

On the other hand, we are also investigating the prediction of stress-strain curves in single and multi structure steels. The stress-strain curves of single structure steels have been summarized by using the Swift equation; $\sigma = a(b + \varepsilon)^N$ where σ and ε refer to the equivalent stress and the equivalent plastic strain, respectively, while a, b and N are constants. In multi-structure steels, we computed flow curves using the secant method based on micromechanics. In the calculations, upper and lower flow curves are obtained depending upon the microstructure, i.e., which constituent is the matrix. In the experiments, it is expected that the different microstructures are obtained by the different heat treatments in a ferrite-martensite steel. This will be related to a wide range of mechanical properties obtained by microstructure control and lead to multi-purpose use in an Fe-Mn-Si-C system. Then, we investigated the upper and lower flow curves in a ferrite-martensite steel in terms of predictions and experiments, respectively.

2. Prediction of flow curves using the secant method

2.1. Outline of calculation

We calculated flow curves of multi-structure steels employing the secant method which was proposed by G.J.Weng[2]. The outline of the calculation is presented in Figure 1. The inclusions are supposed to be spherical particles and the calculation is divided into three deformation stages. The stage I deformation is the elastic deformation where both the matrix and inclusion undergo elastic deformation. Stage II deformation is elastoplastic, where if the matrix yields first the stage IIA would be computed while if the inclusions yield first the stage IIB would be done. The stage III deformation is where both of constituents deform plastically. It is necessary for the secant method to employ the Eshelby's equivalent inclusion principle, the Mori-Tanaka's average stress concept and the Hencky's plastic flow rule.

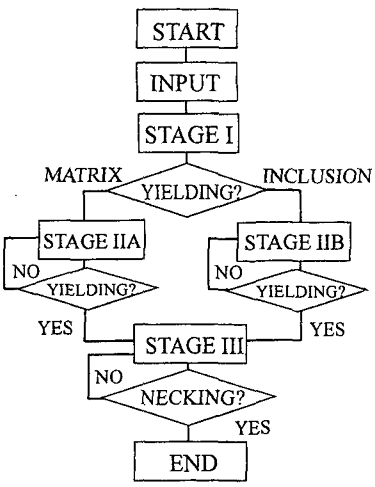
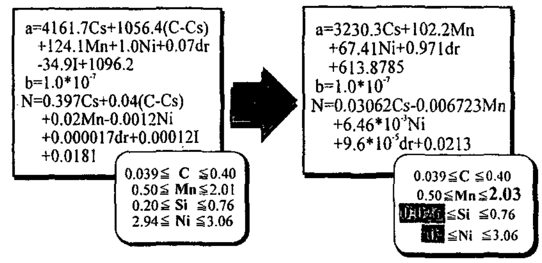


Fig.1 Calculation flow chart for prediction of flow curves in dual microstructure steels.

2.2. Flow curves of constituents

The important data for inputting in the calculation are the elastic moduli, a , b and N of the Swift equation and inclusion volume fraction. The data of a, b and N in the single structure steels have been established by ISIJ co-research by properties prediction working group, as functions of the chemical compositions, microstructural factors and process parameters[3].

Here, we re-investigated the formula of martensite steels because the prediction accuracy was insufficient for our alloy. We distinguished the data on the as-quenched martensite from that on the tempered one because of the difference on microstructure. The re-assessed a, b and N of the Swift equation are presented in Figure 2. Concerning the data on ferrite, we adopted the ISIJ working group's results.



(a) Previous range (b) Extended range

Fig.2 Extension of chemical composition range(mass%) in the data base of martensite.

3. Experimental procedure

The chemical composition of a steel used in this investigation was listed in Table 1. As illustrated in Figure 3, ferrite or martensite matrix steel could be obtained by two types of heat treatments. According to preliminary experiments, we can expect that ferrite becomes the matrix by heat treatment A while martensite does in heat treatment B.

Table 1 Chemical compositions of steel used in the investigation(mass%) and transformation temperatures.

C	Si	Mn	P	S	Cu	Al	N	Ae_1	Ae_3	Ms
0.16	0.41	1.43	0.014	0.004	0.01	0.027	0.028	719(℃)	847(℃)	437(℃)

The heat treatments illustrated in Figure 3 were given to the samples using an electric furnace and a salt bath. Microstructures were examined by means of light microscope. Several microstructural factors such as volume fraction, grain size and so on were determined. Small-sized plate tensile test specimens of with 1.5 mm thick and 30 mm parallel part length were prepared. Tensile tests were carried out with an initial strain rate of $2.78*10^{-3}$/s, at room temperature.

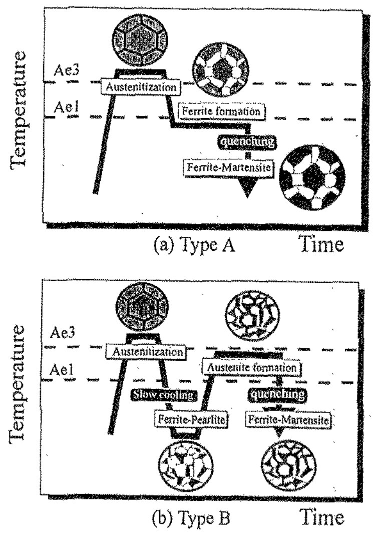


Fig.3 Two kinds of heat treatments used in the investigation.

4. Calculated and experimental results and discussion

The calculated stress-strain curves of a ferrite-martensite steel (ferrite:martensite = 50:50) are presented in Figure 4. By exchanging the matrix from ferrite to martensite, the upper and lower flow curves were obtained. Since ferrite and martensite are very different in strength, there is a big gap between the upper and the lower flow curves. From this calculated result, it is understood that the stress-strain curves are greatly influenced by the microstructure morphology. So it is expected that a wide range of mechanical properties can be obtained, and this will lead to expansion of the multi purpose use in an Fe-Mn-Si-C system.

The microstructures which were obtained by heat treatment A and B were presented in Figure 5. The matrix of the microstructure produced by heat treatment A is ferrite. On the other hand, in heat treatment B martensite colony is continuous along prior ferrite grain boundaries: the matrix is martensite. It is thought that the so-called percolation takes place following the change of martensite volume fraction in the microstructure of heat treatment B.

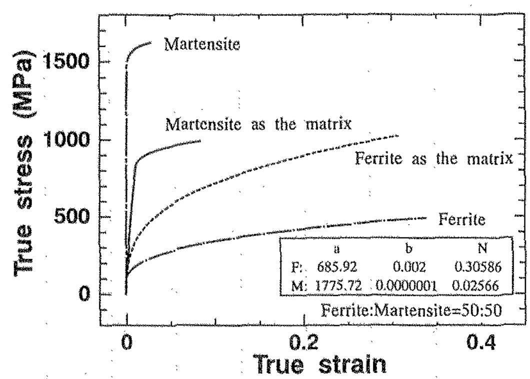
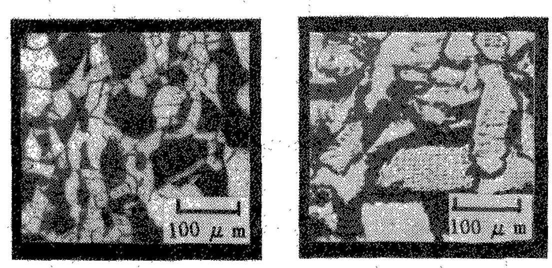


Fig.4 Examples of calculation of flow curves in ferrite-martensite steels, where the material constants, a, b and N, in the Swift equation for martensite and ferrite were predicted as shown in an inserted table.



(a) Type A (b) Type B

Fig.5 Microstructures observed in heat treatments of type A and B.

The comparisons between the calculated and the measured stress-strain curves are presented in Figure 6(heat treatment A) and Figure 7(heat treatment B). As for overall of the stress-strain curves in Figure 6, it is found that the calculated flow curve is closely related to the measured one. But in the calculation of uniform elongation and tensile strength, the calculated data are not in agreement with the measured ones. In terms of this discrepancy, it is suggested that in the calculation the prediction accuracy of the stress-strain curves of single structure steels caused this disagreement. And as to the prediction accuracy of the stress-strain curves of single structure steels, we have to continue to investigate. On the other hand, in Figure 7 the overall of the calculated flow curve doesn't agree with that of the measured one.

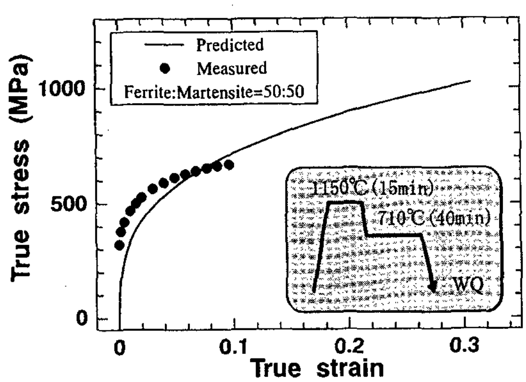


Fig.6 Comparison between predicted and measured stress-strain curves in a ferrite-martensite steel (heat treatment A).

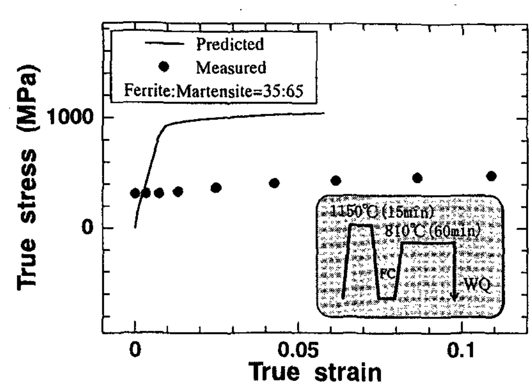


Fig.7 Comparison between predicted and measured stress-strain curves in a ferrite-martensite steel (heat treatment B).

The magnitude of the flow stress at 1% plastic strain in Figure 8 shows how the flow stress of the multi-structure steel is affected by its matrix. First, it is clear that 1% proof stress changes much by the exchange of the matrix from the calculated results. We made clear that the measured data with ferrite matrix were in agreement with the calculated ones. In the case that the matrix was martensite, the measured data were in agreement with the calculated data when the volume fraction was more than 80%.

In terms of these comparison between the predicted and the measured in heat treatment B, it is believed that a whole tension specimen is not controlled to the aimed microstructures that martensite colony is connected along the prior ferrite grain boundary to result in the matrix. Hence, it is thought that the microstructure was neither ferrite matrix nor martensite matrix ; these are something between them. As for such microstructures, there is no ways to compute the flow curves at present. On the other hand, to treat this problem in terms of microstructure control, it is necessary to examine the heat treatment method more deeply. If the complete martensite matrix microstructures are obtained, the measured data will be coming to the predict data regarding the overall flow curves or 1% proof stress. The investigation on this point is now on going.

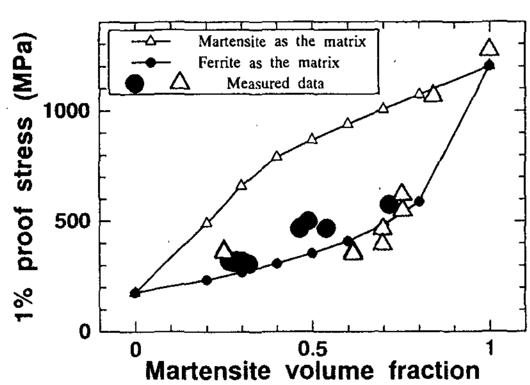


Fig.8 The 1% proof stresses of ferrite-martensite steels as a function of martensite volume fraction.

5. Summary

From this investigation, we have obtained the following conclusions.

(1). In the calculation of stress-strain curves, we can indicate the upper and lower flow curves associated with microstructure variation. A possibility to make a range of properties wider has been suggested.

(2). In the experiments, it is found that two types of microstructures that correspond to the upper and the lower flow curves are obtainable.

(3). In comparison between the calculated and the measured stress-strain curves when the matrix is ferrite, the overall tendency agrees well. But when the matrix is martensite, the agreement is not good. As to this point, we have to improve the heat treatment method.

References

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