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A STUDY OF DEFORMATION CHARACTERISTICS OF Mn-V DUAL PHASE STEEL

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Abstract

The deformation characteristics of dual phase steels have been investigated. The true stress-strain curves were calculated from conventional stress-strain curves measured in Instron 1251. Three empirical formulae were used to approach these curves and C-J method was used to analyze them respectively. It is found that there is a "double n" characteristic in the uniform deformation stage. Based on the results of calculation and observation of microstructure, it is suggested that deformation and work-hardening characteristics in the uniform deformation stage of dual phase steels may be described with what we called "Ashby-Mileiko's comprehensive theory", i.e. initial work-hardening due to incompatibility of two phases may be explained by Ashby's theory. After the strain and work-hardening in the ferrite reached to certain extent martensite began to deform. In this stage the deformation characteristic of dual phase steels may be described by Mileiko's theory which has been used to explain the strengthening mechanism of composite. According to this comprehensive theory in order to increase the initial work-hardening rate and uniform elongation of dual phase steels, it is necessary that under the given reasonable martensite volume fraction, the size of martensite island and ferrite grain should be reduced, the amount of lath martensite in martensite island should be increased and martensite island should be distributed as evenly as possible.

I. INTRODUTION

LOW carbon or HSLA steels which have been intercritically heat treated or specially hot-rolled to produce a martrix of ferrite with 10-30% martensite islands are referred to as dual phase steels. They exihibit continuous yielding, i.e. no sharp yield point, and a relatively low yield stress togrther with a rapid rate of work-hardening, especially initial one, and high elongation (~30%) which gives excellent formability.[1-5]

These characteristics of dual phase steels are closely related to the microstructure features, such as volume fraction of martensite (MVF), the size of martensite island, the fine structure of martensite and ferrite. Some theories[6-10] have attempted to explain the relationship between the properties and microstructure of dual phase steels. However, the relationship between initial work-hardening and true uniform strain and microstructural features of dual phase steels needs to be further studied. The aims of this paper are to study the deformation characteristics of Mn-V dual phase steel under uniaxial tension and relate these to the microstructural features to look for the mechanism of deformation of dual phase steel.

II. EXPERIMENTAL PROCEDURE

A. The experimental steels are Mn-V steels of different carbon contents. The chemical compositions are as follows : 0.10, 0.16, 0.19, 0.29% C, 0.44% Si, 1.30~1.31% Mn, 0.012% P, 0.007% S and 0.05% V. The purpose of varying carbon content is to produce different MVF and different carbon content in the martensite of dual phase steels.

The steels were induction-melted and cast as 22kg ingots, forged to 14 mm dia. bars. After normalizing these bars were machined into 5 mm dia. x 30 mm long blanks which were annealed respectively at 730°; 750, 780, 800, 820°C for 1 hour then water quenched. The metallographic specimens were heated together with these different batches.

B. The tensile specimens were tested on an Instron 1251 machine at a crosshead speed of 1 mm min.^{-1}. Load applied and elongation of specimen were recorded continuously.

C. By using electronic computer the conventional stress-strain curves were converted into true stress-strain curves. Regression analysis or iterative analysis of the uniform elongation stage of these curve by Hollomon, Ludwik and Swift equations were made. By using microcomputer or two degrees three points Lagrangian interpolation method to find out the numerical derivation $\frac{d\sigma}{d\varepsilon}$ (or $\frac{\Delta\sigma}{\Delta\varepsilon}$) of all points in order to use C-J method to analyze true stress-strain curves.

D. According to method suggested by Balliger and Gladman[9] the true strain in the second phase were measured. The specimens used for optical metallography and electron metallography were prepared as mentioned in reference[11].

The volume fractions of all phases were measured by point counting method (a part of specimens was measured by Leitz image analyzer). The amount of martensite islands per unit area was measured in the same field of view in which the MVF was measured. Assuming the second phase being spherical and statistically distributed the diameter of martensite island was calculated by the formula $d = 1.382\, n^{-\frac{1}{2}} f^{\frac{1}{2}}$ where f is the MVF, n is the number of martensite island per unit area.

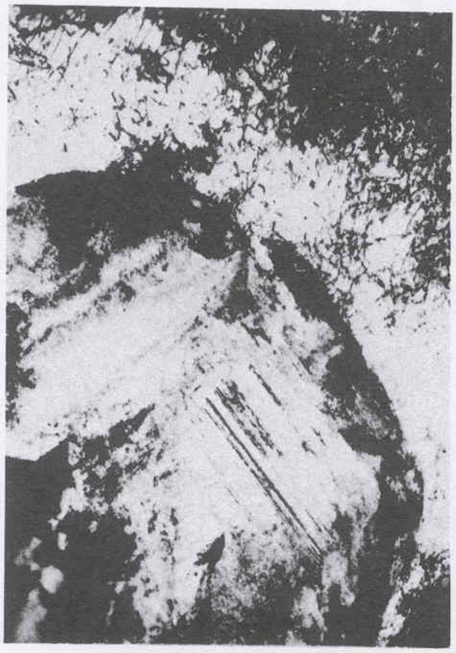
III. EXPERIMENTAL RESULTS

A. Microstructural parameters of Mn-V dual-phase steels after different intercritical annealing processes are listed in Table 1. At lower intercritical annealing temperature the martensite islands consisted basically of twin martensite (Fig.1). As intercritical annealing temperature was increased, the amount of plate martensite decreased and that of lath martensite increased. At 800°C martensite islands consisted basically of lath martensite (Fig.2).

B. The results of computer analysis indicated that using two Hollomon's equations to describe deformation character

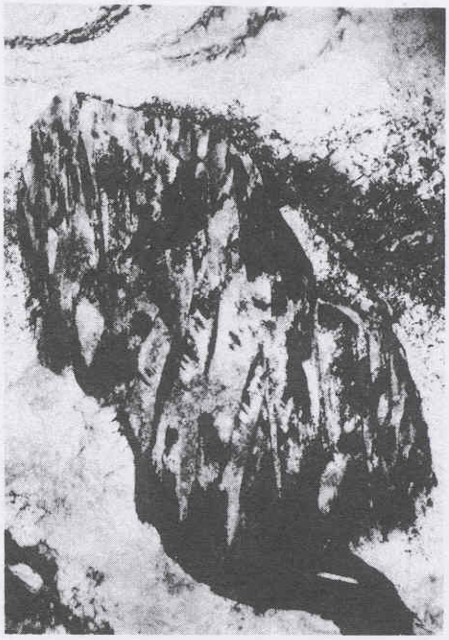
Table 1 Microstructural Parameters of Different Intercritically Annealed Specimens

Specimen Number	Heat Treatment	MVF, %	Mean Diameter of Martensite Island, μm	$\sqrt{\frac{f}{d}}$, $\mu m^{-\frac{1}{2}}$
11	730°C W.Q.	12.5	2.62	0.223
21	730°C W.Q.	23.1	3.06	0.274
31	730°C W.Q.	30.2	4.02	0.274
41	730°C W.Q.	46.4	6.20	0.273
12	750°C W.Q.	19.3	3.50	0.233
22	750°C W.Q.	35.2	5.80	0.246
32	750°C W.Q.	41.5	6.06	0.260
13	780°C W.Q.	20.1	4.00	0.224
23	780°C W.Q.	40.2	6.12	0.256
33	780°C W.Q.	56.3	6.50	0.293
43	780°C W.Q.	80.2	6.80	0.343
14	800°C W.Q.	28.1	5.02	0.236
15	820°C W.Q.	50.3	8.10	0.243



Specimen No.11 TEM x30000

Fig.1— Twin martensite island and dislocations in ferrite.



Specimen No.14 TEM x15000

Fig.2— Lath martensite island and dislocations in ferrite.

ristics in the uniform elongation stage of dual phase steel the error of mean square was small and the relative coefficient was high. Using $\ln\sigma$ and $\ln\varepsilon_p$ (where σ and ε_p are true stress and true plastic strain) as coordinates to plot the calculated results of computer analysis we found that all the $\ln\sigma - \ln\varepsilon_p$ curves of Mn-V dual phase steels had an inflexion point i.e. there was a double n characteristic in the uniform elongation stage of dual phase steel (Fig.3). The value of first n was higher than that of the second which was equivalent to true uniform strain (ε_u or n_u). The position of inflexion point depended on the MVF and morphology of martensite. The larger is MVF, especially volume fraction of lath martensite, the more will the inflexion point move towards lower strain. The values of n_1 and n_2 of different intercritically annealed specimens were listed in Table 2.

C. The results of C-J analysis[12] (i.e.

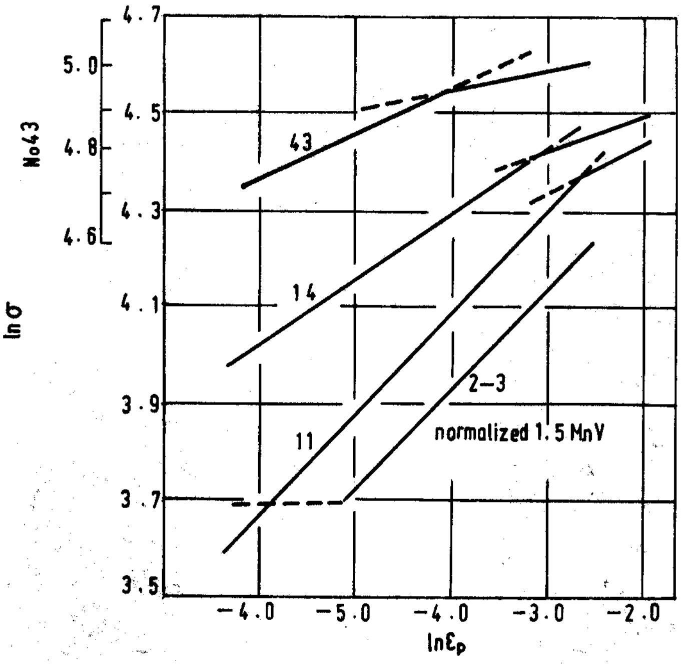


Fig.3— The flow characteristics of specimens after different intercritical annealings.

Table 2 Double-n Characteristics in the Stage of Uniform Elongation of Specimens after Different Intercritical Annealings

Number of Heat Treatment	11	21	31	12	22	32	13	23	33
n_1	0.218	0.189	0.107	0.180	0.172	0.152	0.152	0.176	0.154
$n_2(n_u)$	0.173	0.125	0.117	0.165	0.114	0.101	0.101	0.145	0.086
Strain at Inflexion point,%	0.080	0.056	0.032	0.076	0.030	0.030	0.026	0.040	0.028

plot ln $\frac{d\sigma}{d\varepsilon}$ vs ln ε_p) of specimens No.11 No.14 were shown in Fig.4.It can be seen that the plot of ln $\frac{d\sigma}{d\varepsilon}$ vs ln ε_p was more sensitive that the plot of ln σ vs ln ε_p to display the double n characteristics in the uniform elongation part of stress-strain curve of dual phase steel.

IV. DISCUSSION

The Main constitutional phases of dual phase steels were plate martensite (or lath martensite) and ferrite. There was strain partioning between these two phases. At the beginning of deformation of dual phase steel the ferrite deformed first whereas martensite remained undeformed so that plastic incompatibility between these phases was large and the work-hardening rate of ferrite was high that meant the value of first n was large.In the second stage of uniform deformation martensite began to deform whereas the degree of plastic incompatibility decreased and correspondingly the work-hardening rate decreased. Hence, it is reasonable to assume that the double-n characteristics of dual phase steel and the position of inflixion point was closely related to the strain partioning of constitutional phase. Based on this argument, in this paper an Ashby-Mileiko's comprehensive theory was suggested to describe the mechanism of initial work-hardening and the next part deformation characteristic in the uniform deformation stage of true stress-strain curve. The definition of this theory is that in the initial work-hardening stage(matrix deformed whereas hard phase remained undeformed) the deformation characteristics of dual phase steel could be explained by Ashby's work-hardening theory. When hard phase began to deform the mechanism of deformation would be explained by Mileiko's theory.

Ashby's work-hardening theory assumes

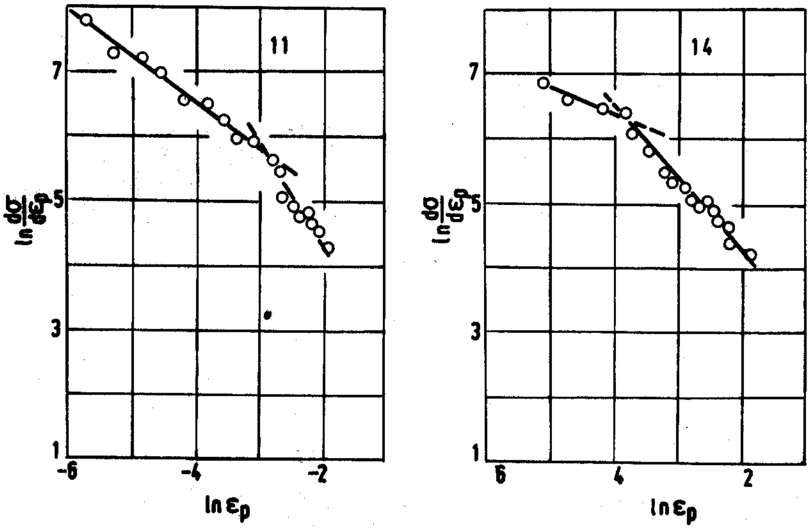


Fig.4—— Crussard-Jaoul analysis of the stress-strain curves of specimens No.11 and No.14

that the principal contribution to work-hardening is due to the interaction of primary, glide dislocations with the secondary dislocation loops which intersect the slip plane[13]. The principal prediction of the theory is the relationship between the true stress σ and true strain ε , given by

$$\sigma - \sigma_0 = kG \sqrt{\frac{bf\varepsilon}{0.41d}} \qquad (1)$$

where σ is the flow stress when strain is ε . σ_0 is a constant, related to the initial flow stress, in this paper it is equal to $\sigma_{0.2}$; K is a constant of the order of 1. G is the shear modules of the matrix, approximately 82400 MNm^{-2}, b is the Burger vector of the matrix dislocation, approximately 0.247 nm, f is the volume fraction of precipitate and d is the average particle diameter.

After calculating the increment of flow stress at ε = 3%* and plotting ($\sigma_{3\%} - \sigma_{0.2}$) vs $\sqrt{f/d}$, a linear relationship was obtained (Fig.5), the slope of which obtained from regression analysis is 486.5 which is close upon 440 calculated by formula (1). It means that Ashby's theory can be used to express the mechanism of initial work-hardening of dual phase steels. However, after martensite began to deform, Ashby's theory which rests on the assumption of hard, equiaxed particles which do not deform or fracture will no more be valid. Therefore, we used Mileiko's model to describe the second stage of uniform strain hardening. Mileiko's model[7] uses a plastic instability approach to des-

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* The strain in most of stamping parts is about 3%.

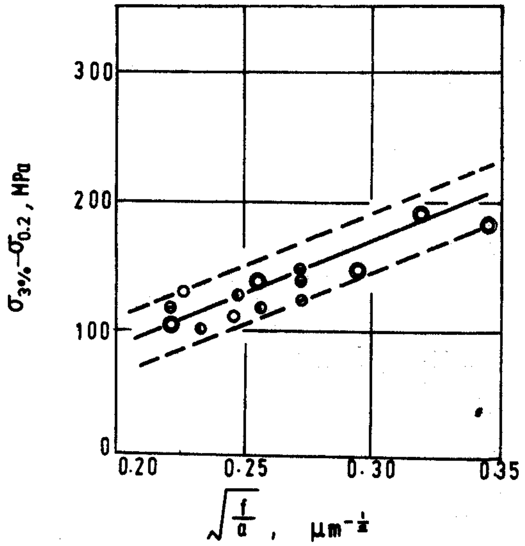

Fig.5—($\sigma_{3\%} - \sigma_{0.2}$) vs $\sqrt{f/d}$.

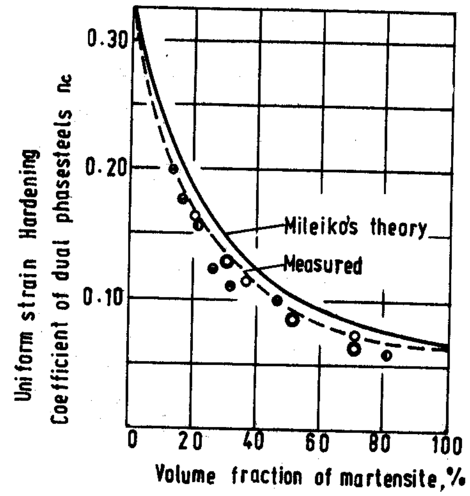

Fig.6— A comparison of observed values of n and true uniform strain with that predicted by Mileiko's theory.[14]

cribe the stress-strain curve of continuous fiber composites from the stress-strain behavior of the individual components. The stress are partitioned by the rule of mixturess and the strain in fiber and the martrix are assumed to be equal. If it is assumed that the martensite in a ferrite/martensite dual phase steel acts like fibers (with a given aspect ratio of approximately 1)aligned in the tensile direction then the Mileiko's model can be applied[7,14].Given the mechanical properties of the two components it is possible to calculate the change in true uniform strain with volume fraction of martensite f_m,from the expression, where n_u and true uniform strain may be used interchangeably[14]

$$f_m = \frac{1}{1+\beta \frac{n_c - n_m}{n_F - n_c} n_c^{n_m - n_F}} \qquad (2)$$

where $\beta = \frac{\sigma_m}{\sigma_F} \frac{n_F^{n_F} \exp n_m}{n_m^{n_m} \exp n_F}$

and σ_m and σ_F are the tensile strengths of the martensite and ferrite respectively, and n_c,n_m and $n_F$are the true uniform strains for the dual phase steel, martensite, and ferrite respectively. A comparison of observed values of true uniform strain n_c of Mn-V dual phase steels. with that predicted by Mileiko's theory[14] was given in Fig.6. Good corelation between the predicted and experimental results is found.

According to Ashby's theory, for the sake of increasing the initial work-hardening rate the MVF should be increased and the size of martensite ialand should be decreased.According to Mileiko's theory,for the sake of increasing uniform elongation the MVF should be decreased and the strength of ferrite should be increased (by decreasing the size of ferrite and martensite) or that of martensite should be decreased (by decreasing the carbon content in martensite) in order to decrease the incompability between these two phases.

From above mentioned arguments it can be seen that using the method of increasing MVF to increase the initial work-hardening rate would be restricted by its deteriorating the uniform elongation. On the contrary, decreasing the size of martensite island would increse both the inintial work-hardening rate and the strength of ferrite and so the uniform elogation of dual phase steels. According to comprehensive Ashby-Mileiko's theory the way of increasing both the initial work-hardening rate and uniform elongation of dual phase steels will be under the given amount of MVF decreasing the size of ferrite and martensite island, making the latter as evenly distributed as possible and increasing the amount of lath martensite in martensite islands.

V. CONCLUSIONS

1. Using electronic computer to calculate the true stress (σ) and true strain (ε) in the uniform elongation stage of Mn-V dual phase steels and plotting ln $\frac{d\sigma}{d\varepsilon}$ vs ln ε_p (so called C-J analysis) or ln σ vs ln ε_p. It can be found that in this stage there appeared a double-n characteristic. The first value of n , i.e. at the initial stage of uniform elongation, is rather high whereas the second value of n is lower than the first one. The strain at the inflexion point between these two parts is affected by the morphology of marten

site and MVF etc.

2. A comprehensive Ashby-Mileiko's theory is suggested to explain the double n characteristics in the uniform elongation part of true stress-strain curve of dual phase steel.The initial work-hardening rate can be explained by Ashby's work-hardening theory and the mechanism of the next stage of uniform elongation can be predicted by Mileiko's theory.
3. In order to increase the initial work-hardening rate and improve uniform elongation the prediction of this comprehensive theory is under given amount of MVF decreasing the size of ferrite and martensite islands, making the martensite island as evenly distributed as possible, as well as increasing the amount of lath martensite in martensite islands.

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