EFFECT OF PRIOR RECOVERY ON THE RECRYSTALLIZATION OF CARBON STEEL

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ABSTRACT
An investigation has been carried out, using optical metallography and hardness measurement methods, to ascertain the effect of prior-recovery heat-treatment on the rate of recrystallization in mild steel. The results reveal a definite correlation between the combined effect of cold-work and degree of recovery on the one hand, and recrystallization tendencies of mild steel on the other hand. Specimens with long-time prior-recovery treatment (up to 120 minutes) show longer recrystallization times than those without pre-recovery, annealing.
It is felt that as a result of prior-recovery, there is a remarkable reduction in recrystallization driving forces, and this ultimately leads to a change of the recrystallization process from the usual "discontinuous" to the characteristically sluggish "continuous" mechanism.

Introduction

Usually, when a metallic material is sufficiently deformed and then subjected to a temperature of at least 0.3 of its melting point, it undergoes primary recrystallization. The recrystallization process is considered to take place in two stages:

(a) a stress-relieving phase, referred to as RECOVERY, and

(b) NUCLEATION and GRAIN-GROWTH stage, consulting the actual (primary) recrystallization

There appears to exist a conflicting notion of the role of recovery during primary recrystallization. Often it is believed that extensive recovery shortens, the recrystallization time [1].1t is to be noted, however, that during the nucleation and grain-growth stage there is real movement of a "reaction front" into the deformed matrix. The energy retained in the matrix during the deformation process is associated with the driving force of the reaction front [2]. Since the intensity of this driving force is known to depend on, among other things, the defect gradient across the reaction front, it is clear that the extent or recovery is bound to influence the kinetics and mechanism of recrystallization.
The aim of this study is to investigate the effect of prior-recovery on the recrystallization kinetics of mild steel. To this end specimens, previously recovery heat-treated at 200°C in a preliminary experiment, were subjected to recrystallization anneallng at 550°C.

Experimental

Material and Heat- treatment:

The material used for this investigation was carbon steel of composition (wt, %), 0.23C; 0.37 Si; 0.53Mn, with Fe as balance.
To reduce the recrystallization complications involved in a two-phase material [3] to a minimum, it was decided to use as starting-point specimen.The pearlitic microstructure, whose recrystallization mechanism had been investigated in earlier work [4].
The pearlitic structure was obtained by heating at 870^0 for 1½ hours and subsequently cooling in air. This was then rolled to varying degrees of deformation (30%, 50%, 75%

reduction in thickness) and then cut to specimen sizes (20 x 10 x 1 mm).

To obtain various degrees of recovery, the specimens were heated at 200°C for different times (20; 30; 120 minutes). Subsequently, the recovery heat-treated samples were subjected to recrystallization heat-treatment at 550°.

With the help of well-established methods for recrystallization analysis (light metallography, hardness-measurements) [5], the times for the onset, progress and end of recrystallization in each specimen were obtained.

Results and Discussion

Preliminary Recovery Heat-Treatment

The hardness-vs-log-time curve from the preliminary recovery heat-treatment is shown in figure 1, with the various % - deformations as parameter. The progressive fall in hardness with time characterizes the gradual stress-relieving reaction going on in the microstructures as a result of dislocation annihilation and rearrangement. The varying hardness levels of the curves arise from the magnitude of each specimen's stored cold-work energy, which increases with %-deformation.

Recrystallization Heat-Treatment Figures 2 - 5 show hardness-vs-time curves for the 550°C recrystallization annealing. The time from the beginning of the recrystallization heat-treatment till the onset of recrystallization (t_{RB} = incubation time) as well as the total time-lapse for full recrystallization (t_{RE}) are indicated on the curves.

The recorded recrystallization times (t_{RB} and t_{RE}) for various degrees of cold-work (%) and prior-recovery periods at 200^{0}C are shown in Table 1.

Table 1: Recrystallization Times (t_{RB} t_{RE} in Minutes) at 550°C

Pre-recovery time in Min. at 200^{0}C	E = 30%		50%		75%	
	t_{RB}	t_{RE}	t_{RB}	t_{RE}	t_{RBE}	t_R
0	25	960	10	12	2	12
10	6	*	5	*	4	*
30	12	*	10	*	6	*
120	35	360	300	30	12	240

"*" indicates that complete recrystallization was not observed within the time of the investigation (360 minutes); apparently, t_{RE} > 360 mins.

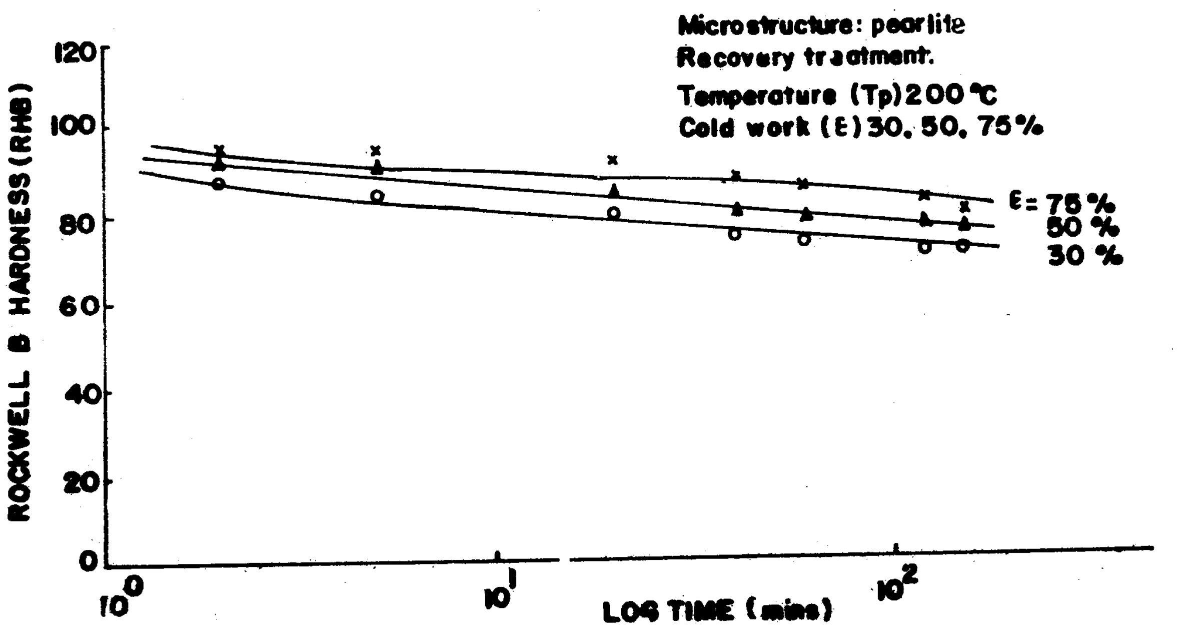

Figure1. Variation of hardness with time during recovery heat-treatment of a specimen having a pearlitic

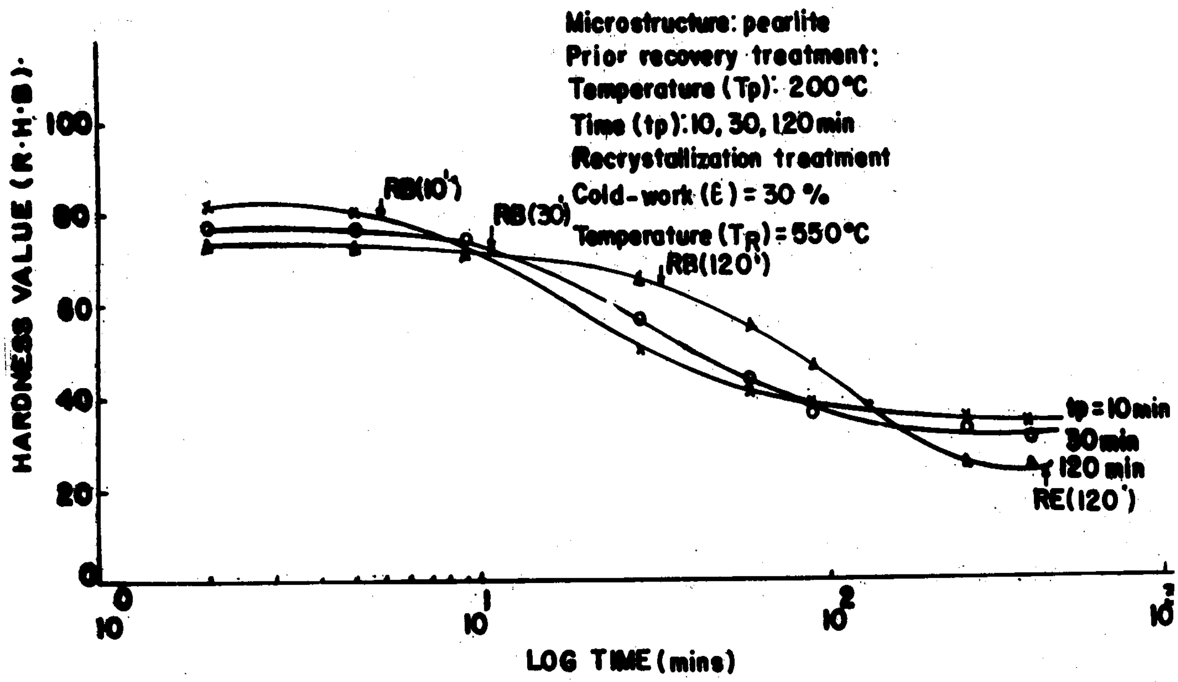

Figure 2. Variation of hardness with time during recrystallization annealing of a pearlitic microstructure after previous recovery heat-treatment for various times, tp. (% Deformation = 30; t_p = 10min, 30min, 120min.)

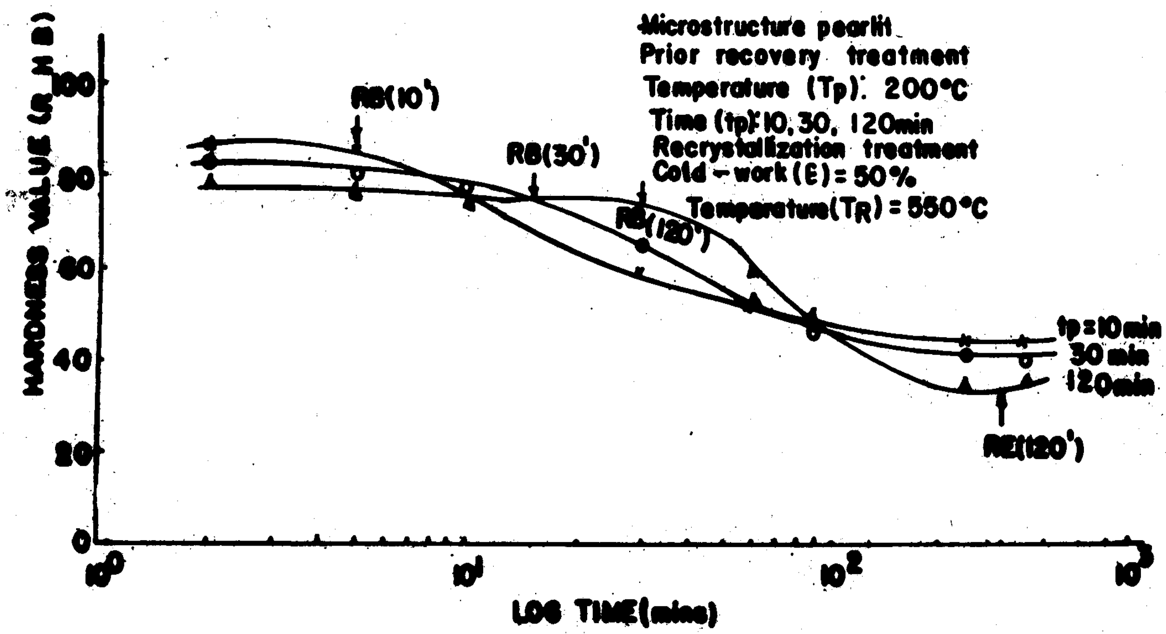

Figure 3. variation of hardness with time during recrystallization annealing of a pearlitic microstructure after previous recovery heat-treatment for various times, tp. (% Deformation = 50; t_p = 10min, 30min, 120min.)

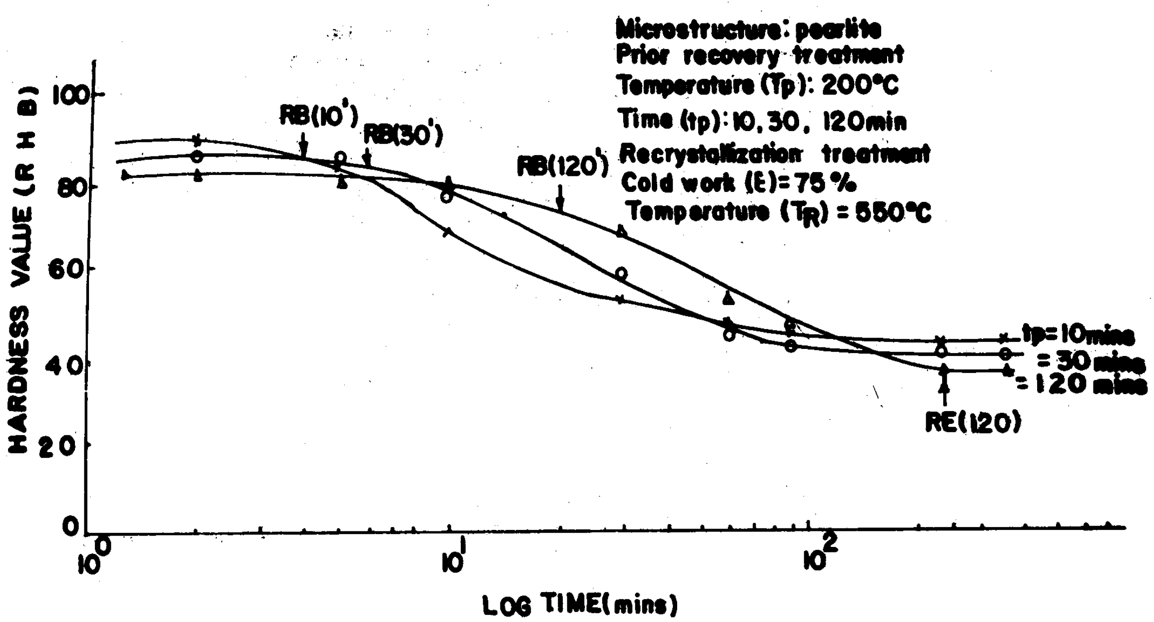

Figure 4. Variation of hardness with time during recrystallization annealing of a pearlitic microstructure after previous recovery heat-treatment for various times, tp.
(% Deformation = 75; t_p = 10min, 30min, 120min.)

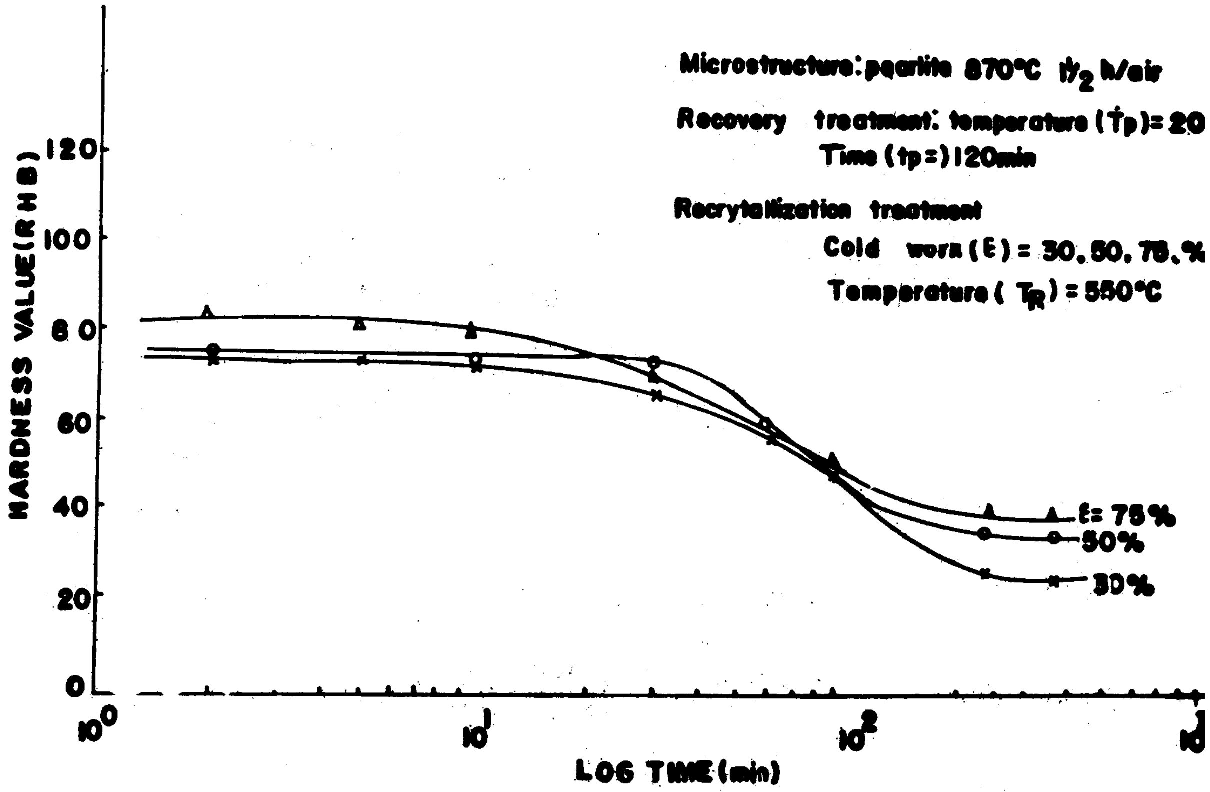

Figure 5. Effect of % Deformation (or degree of cold work) on the variation of hardness with time during recrystallization heat-treatment of a pearlitic microstructure after previous recovery heat-treatment (recovery time, t_p maintained at 120 minutes in all cases.)

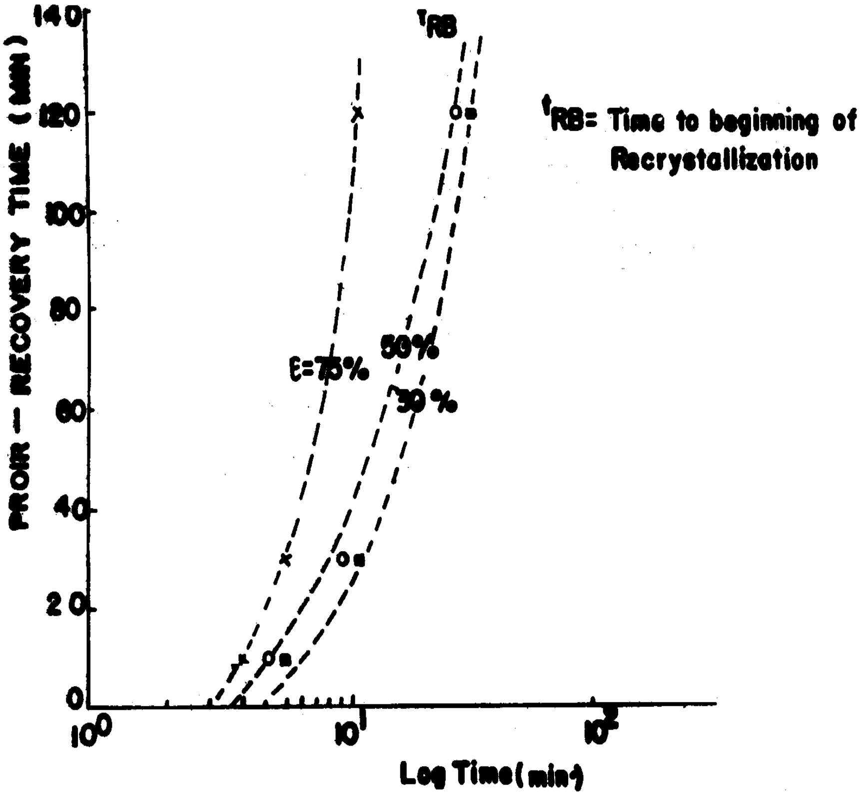

Figure 6. Effect of extent of prior-recovery on incubation time, t_{RB} for specimens with various degrees of cold work, (ε).

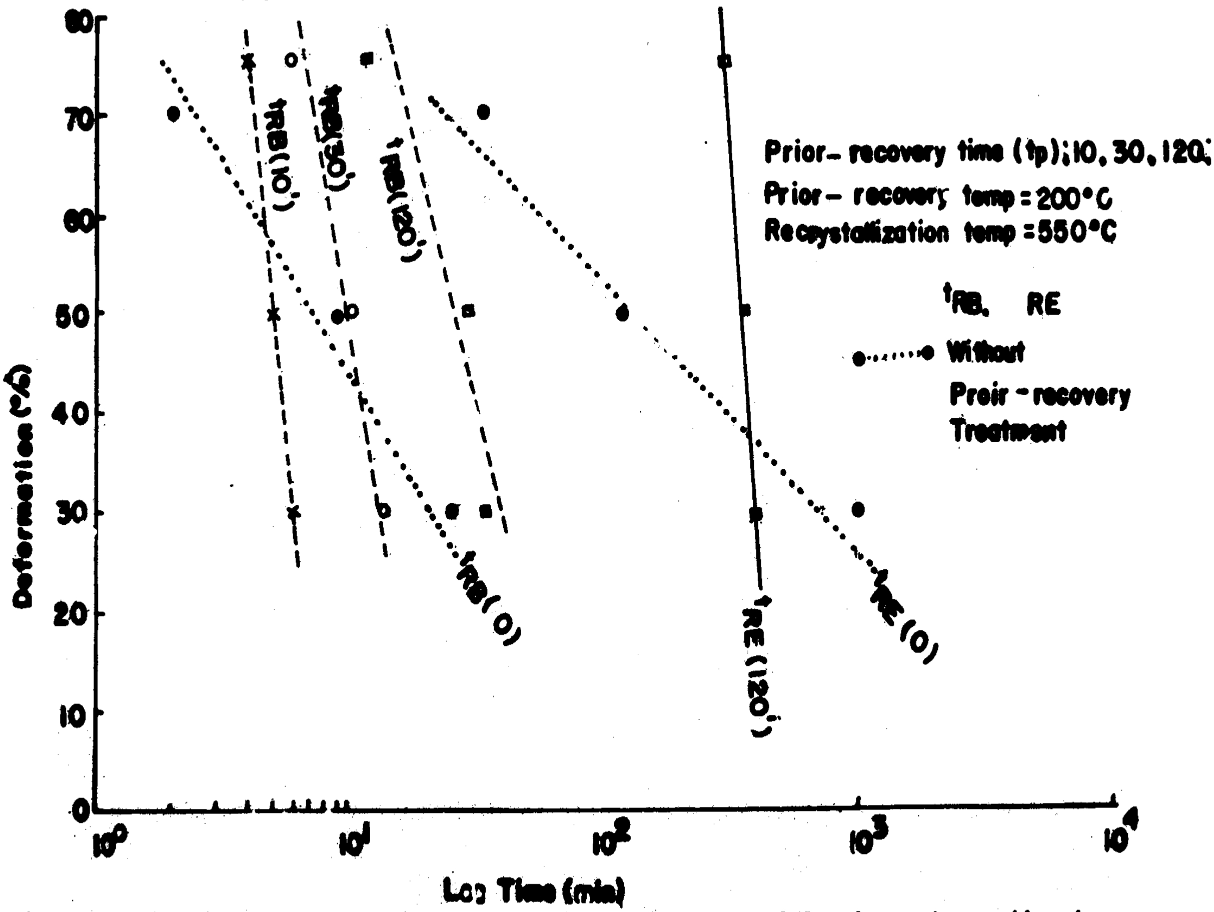

Figure 7. Effect of extent of deformation on recrystallization times, t_{RB} and T_{RE}, for specimens with and without prior recovery treatment.

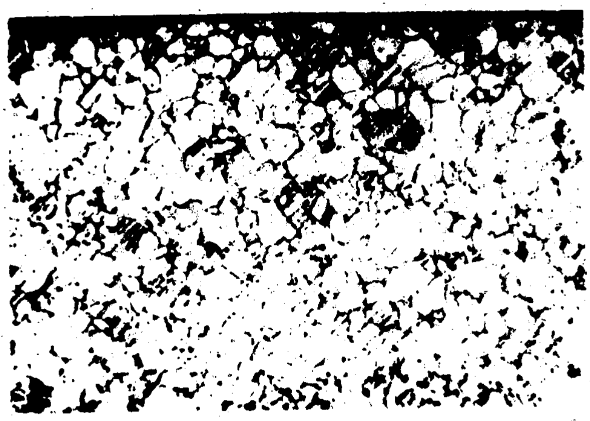

Figure 8. Recrystallized microstructure of a specimen subjected to high deformation and prolonged prior-recovery. (75% Deformation, 120 minutes prior-recovery at 200°C; 360 minutes recrystallization annealing at 550°C; Optical micrograph, mag. 400X)

The results show a general increase in recrystallization times (t_{RB} t_{RE}) with increasing degree of prior-recovery. Recrystallization appeared to start early in the short-time prior-recovery specimens, but later got so slowed down that the end (t_{RE}) was not observed within the period of the experiment. The long-time prior-recovery specimens on the other hand, started sluggishly and became fully recrystallized, though after a very long time (240 minutes as against 12 minutes for the specimens 75% - deformed and not prior-recovery-treated).

Figure 6 shows the effect of the degree of deformation and extent of prior-recovery on the incubation time; while in Figure 7, t_{RB} and t_{RE} of the prior-recovered specimens are presented along with those of specimens not previously recovery - treated.

For any degree of prior-recovery the incubation time increased with decreasing cold-work (figure 6). Increasing the degree of prior-recovery had the effect of shifting the incubation limes to longer periods; in fact, for all deformations, the fully prior-recovered specimen (120 minutes recovery time) started in all cases, later than the untreated specimen (figure 7). For specimens of intermediate prior-recover treatment period (10 minutes, 30 minutes) there existed a corresponding critical deformation, ε_o below which prior-recovered specimens started to recrystallize earlier than the untreated ones. This critical deformation appeared to decrease with increasing degree of prior-recovery. In an earlier study of the pearlitic microstructure [5], it was observed that:

(a) the mechanism of recrystallization was exclusively that of a discontinuous reaction,

(b) the ferrite-pearlite phase-boundary was a preferential recrystallization nucleation site,

(c) the recrystallization times (t_{RB} t_{RE}) drastically decreased with increasing deformation.

The observation made in this investigation can be explained by examining the implication of prior-recovery on the recrystallization mechanism.

Heating the deformed material at a temperature (2000) far below the recrystallization temperature of mild steel, has the effect of reducing the over-all dislocation density and the net driving force on a potential reaction front. This situation enhances the continuous mode of recrystallization mechanism. It can therefore be easily seen that increased degree of prior-recovery leads to subgrain-growth which, in a pearlitic structure, is not impeded by second-phase particles, and consequently, gives rise to full recrystallization (figures 2-4). At low cold-work (less than about 36%), this situation can even lead to faster recrystallization process (figure 7) than in the case of the conventional "strain-induced" mechanism usually associated with the low deformation range [2]. At high deformations and prolonged prior-recovery, the recrystallization process can lead to a fine –grained structure, as can be seen from figure 8. This is also reflected in the high hardness values of the 75% - deformation curve in figure 5. At intermediate prior-recovery periods (10 minutes, 30 minutes) it is felt that a mixed recrystallization mechanism (continuous and discontinuous) is operational, leading to a rather accelerated onset of recrystallization (Table1). With continued heating at the recrystallization annealing temperature, the dislocation – induced driving forces decresse, with few subgrains, acquiring enough disorientation (15^0 – 20^0) which is necessary for recrysalliization. This state of affairs leads to sluggish and incomplete recrstallizaiton (figures 2 - 4).

CONCLUSISION

It has been shown that prior-recovery heat-treatment of a cold-worked pearlitic structure has the effect of reducing its recrystallization tendencies.

At low cold-work (less than 36%) and intermediate prior-recovery period (up to 30 minutes at 200^0), however recrystallization starts rather earlier than would be expected in non-pre-treated material, but to go to completion.

It is felt that prior-recovery, with its attendant dislocation rearrangement /annihilation, leads to a weakening of the driving forces necessary for discontinuous recrystallization, and thus gives rise to sluggish recrystatlization process, namely the continuous mechanism.

References

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