STRAIN INDUCED PRECIPITATION IN MICROALLOYED STEELS CONTAINING NB, TI AND V

Ersoy ERİŞİR

Department of Metallurgical and Materials Engineering, Kocaeli University, Turkey, eerisir@kocaeli.edu.tr

Abstract

The strengthening effects of microalloying elements make microalloyed medium carbon steels suited for high-strength-steel automotive applications. By combining the strengthening mechanisms of the grain refinement and the precipitation hardening, microalloying elements may shorten the processing times of automotive parts. Microalloyed medium carbon steels have high strength by precipitation hardening effect of vanadium. The aim of this study is to investigate the strain induced precipitation during hot deformation of a niobium microalloyed steel. In order to study the strain induced precipitation, interrupted compression tests were performed. The precipitation kinetics of a 0.34%C-0.045%Nb-0.019%Ti-0.037%V steel were examined at 875-1100 ºC. The results were analyzed using offset method. Precipitation-time-temperature diagrams were drawn using the analyzed data.

Keywords:

Microalloyed steels, strain induced precipitation, hot deformation, fractional softening, kinetics

1. INTRODUCTION

Microalloyed medium carbon steels are used in hot forged parts for automotive industry. Due to good balance of strength and toughness and relatively easy process route, microalloyed forging steels find applications such as crankshaft, connection rods, wheel hubs, rams, spindles, etc. [1-4]. The mechanical properties of microalloyed forging steels can be supplied in the as forged condition without any quenching or tempering [5]. Thus, the use of microalloyed forging steels has expanded owing to savings of time and manufacturing costs [6]. In contrast to quenched and tempered martensitic steels, the strength and toughness of microalloyed forging steels should be obtained by its chemical composition and during the thermomechanical forging process. The microstructure after the forging process is generally ferritic-pearlitic. Therefore, the mechanical requirements can be provided by the strengthening mechanisms of grain refinement and precipitation hardening by microalloying elements. The precipitates offer grain size control through the pinning of grain boundaries with microalloying element carbonitrides control during the preheating and forging steps. On the other hand, the precipitation hardening is obtained by fine carbonitrides formed in austenite and especially in ferrite, which causes also a decrease in toughness of steels [7,8]. In order to improve the strength and toughness, many studies have been carried out on the development of processing and microstructure of microalloyed forging steels. González-Baquet et al. [5] found that it is possible in effective way to improve strength and toughness by a two-step-cooling processing that results in a microstructure is formed polygonal ferrite and bainite. An increase of yield strength and toughness are achieved by grain refinement. Rasouli et al. [9] developed an acicular ferrite microstructure which improves the strength and ductility of 30MnVS6, simultaneously via air cooling at the rate of 3 ºC/s.

In order to improve the toughness, the parameters of the forging process must be optimized. This is especially important when the final microstructure is produced directly by the forging, and no subsequent heat treatment is carried out. Therefore, an adequate flow behavior characterization of the material under hot working conditions is an important task that is necessary to be executed to optimize and to control the design of the components [10-12]. The recrystallization is inhibited by the pinning forces exerted by precipitates of microalloying elements Ti and V, or solute dragging effect due to segregation of alloying elements, especially Nb [12-15]. Thus, one of the most important aspects to be studied is the accurate assessment of strain-induced precipitation and recrystallization during deformation. Despite large amount of efforts invested into the behaviors of 30MnVS6 steel, the kinetics of recrystallization and strain induced precipitation in the hot forged 30MnVS6 steel still need further investigation. In this study, the recrystallization and strain induced precipitation behaviors in 0.34%C-0.045%Nb-0.019%Ti-0.037%V steel were investigated by isothermal interrupted hot compression tests.

2. EXPERIMENTAL

The chemical composition of the steels used in this study is given in **Tab. 1**. Cylindrical specimens were machined with a diameter of 10mm and a height of 15mm. In order to minimize the frictions between the specimens and die during hot deformation, the flat ends of the specimen were recessed to a depth of 0.1mm to entrap the lubricant of MoS. To study the progress of static recrystallization and strain induced precipitation, interrupted hot compression tests were performed on a computer-controlled, servo-hydraulic thermomechanical simulator. This involves performing an initial compressive deformation, unloading for different inter-pass periods, and then applying a second deformation (**Fig. 1**). The resulting true stress and true strain curves are then analyzed to determine the softening ratio, which has formed during the inter-pass period.

Table 1. Chemical composition of the material.

C	Si	Mn	P	S	Cr	Ni	Al	Cu	Nb	Ti	V	N, ppm
0,34	0,66	1,14	0,010	0,020	0,149	0,024	0,018	0,019	0,045	0,019	0,037	141

In **Fig. 1**, the specimens were heated to 1250 ºC at a heating rate of 10 ºC/s and held for 400 s. Then, the specimens were cooled to the deformation temperature T_1 at 5 ºC/s and held for 30 s to eliminate thermal gradients. Different deformation temperatures between 875 ºC and 1100 ºC at a strain rate of 10 s^{-1} were used in interrupted hot compression tests with a deformation degree of 0.35 in specimen height. The deformation temperatures, the strain rate and the deformation degree are same for the initial and second deformation. During the inter-pass periods, the specimens were held at the deformation temperature for delay time of (2–2.000) s to enable strain induced precipitation and recrystallization to progress. The second deformation was applied to measure the softening fractions, and then the specimens were rapidly quenched in N_2 gas.

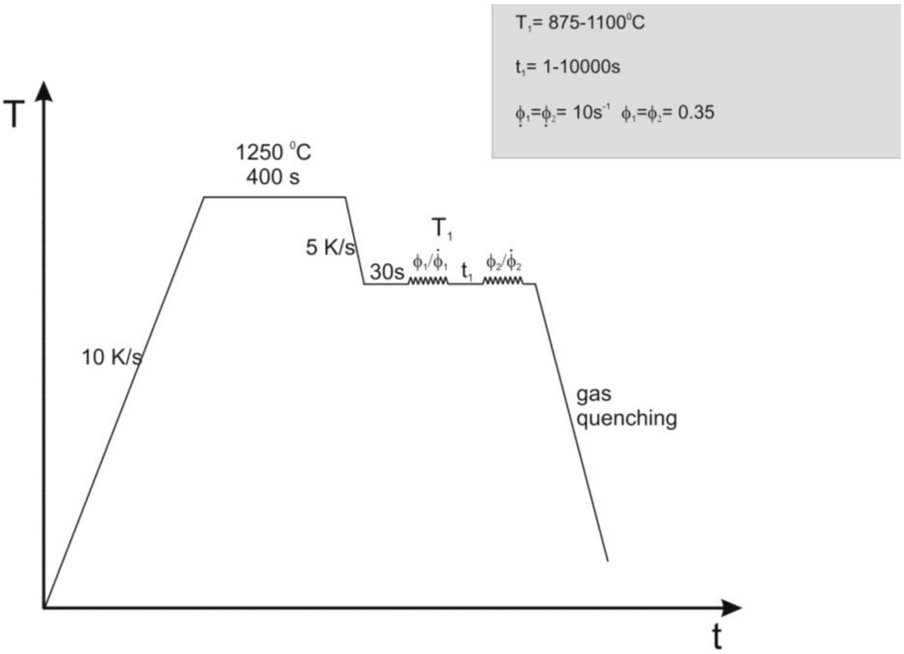

Fig 1. Experimental procedure for interrupted hot compression tests.

3. RESULTS AND DISCUSSION

Decreasing deformation temperature generally increases the flow stress of the steels. The rise of true stress results in higher forging loads and shorter life-time of forging tools [1]. Maximum flow stresses are plotted for different deformation temperatures between 875 and 1100 ºC in **Fig. 2**. Maximum flow stress shows a sharp decrease with increasing deformation temperature.

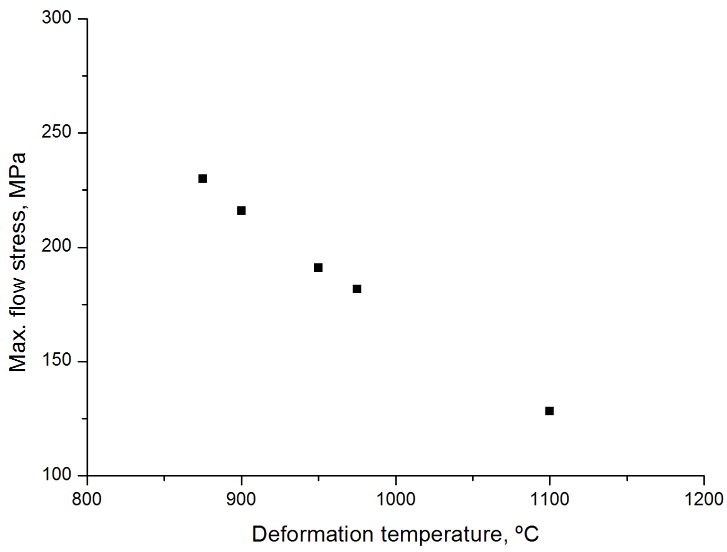

Fig 2. Maximum flow stress after the initial deformation step (deformation rate: 10 sn^{-1})

3.1 The effect of deformation temperature on fractional softening behavior

The interrupted compression test is based on the principle that the yield stress is a sensitive measure of microstructural changes at high temperatures. When the inter-pass period is long enough between two deformation steps, full recrystallization and softening can be take place and leads to same flow curves for the initial and second deformations. In **Fig. 3**, true stress and true strain curves were given for different inter-pass periods. İncreasing the inter-pass time from 2 to 2.000 s results in decreasing peak stress and strain compare to the extrapolation of the first curve. On the other hand, for interpass times of 50 and 100 s, the values increase which indicate to the precipitation between deformations.

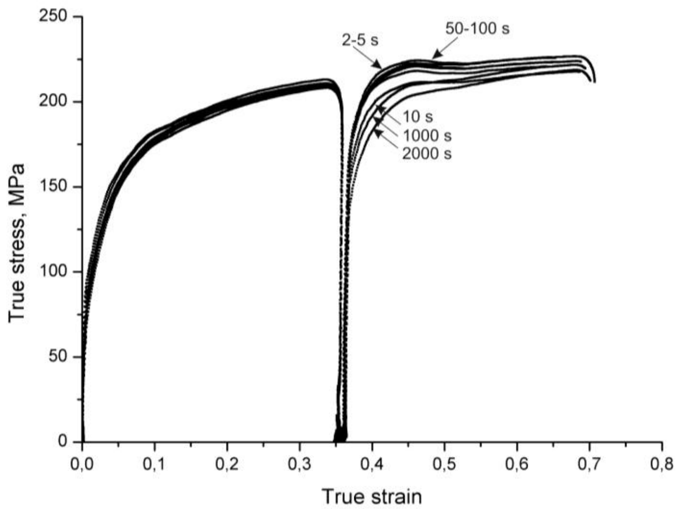

Fig 3. True stress-true strain curves after different inter-pass periods at 950 ºC.

In order to quantify the amount of softening between two deformation steps, the offset method (2% offset) can be used. In offset method, the results are insensitive to the softening effect of recovery and fractional softening is then attributable to static recrystallization [16]. The fractional softening X_{off} is given as followings;

$$X_{off} = \frac{\sigma_m - \sigma_2}{\sigma_m - \sigma_1} \quad (1)$$

where σ_m is maximum flow stress at the flow curve of initial deformation, σ_1 is the stress at the offset of 2% strain at initial deformation, and σ_2 is the stress at the offset of 2% strain at second deformation. In **Fig. 3**, the kinetic curves were presented for softening ratio and interpass time determined using offset method. It can be seen that increasing temperature makes easier the kinetics of static recrystallization. The curves at 1100 ºC and 975 ºC showed S-shaped behavior. However, decreasing the temperature below 950 ºC, a plateau appears on the curves. The plateau is caused by strain induced precipitation and its beginning and end have been identified with the start and finish of precipitation [12,14,16,18,19]. However, these are very approximate criteria, since before and after the plateau the curve shows kinetics similar to the curves corresponding to higher temperatures which do not show a plateau.

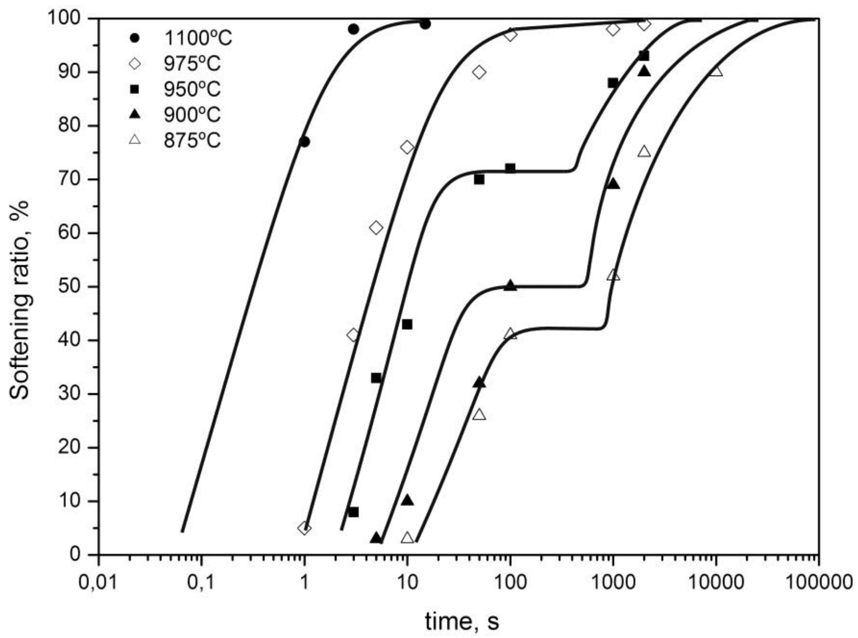

Fig 4. Kinetic curves of fractional softening vs interpass time between two hit. All samples were deformed at $10s^{-1}$ to the prestrain of 0.35.

3.2 Precipitation-Time-Temperature (PTT) Diagram

Precipitation-time-temperature (PTT) diagram was consequently obtained by using the kinetics curves. From the curves, it is possible to deduce the start time (Ps) and finish time (Pf) of the strain induced precipitation. The PTT diagram is given in **Fig. 4**. It can be seen that SCRT (static recrystallization temperature), asymptote of Ps and Pf curves, is determined as 960 ºC. SCRT indicates highest temperature of strain induced precipitation. On the hand, Ps curve has given a nose temperature of 940 ºC at 28 s.

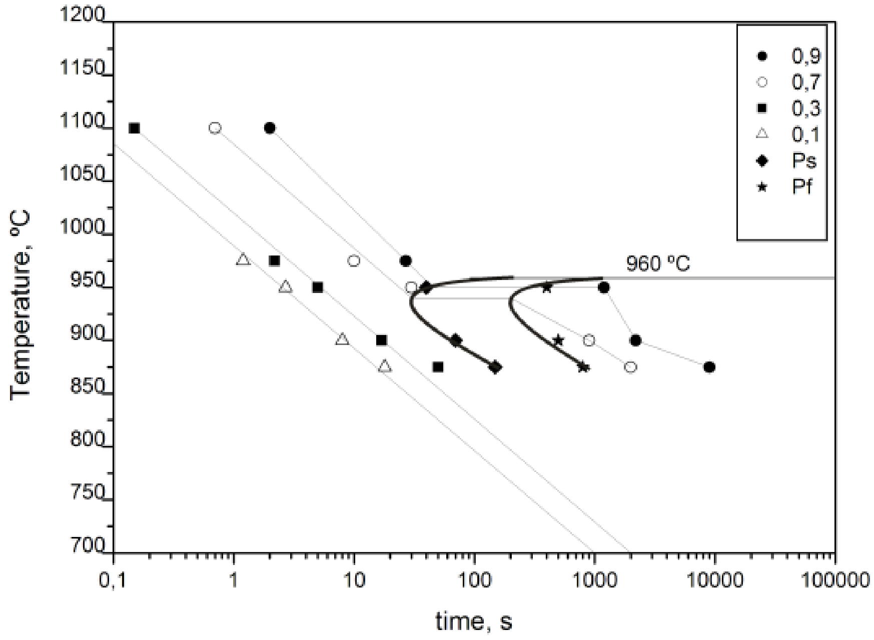

Fig 5. PTT diagram

4. CONCLUSION

Hot compression simulations have been used to determine the effect the deformation temperature on the kinetics of recrystallization and strain induced precipitation for 0.34%C-0.045%Nb-0.019%Ti-0.037%V steel. The results can be summarized as follows:

-Strain induced precipitation may occur in periods from 28 seconds to a couple of minutes at temperatures lower than 960 ºC.

-At high temperatures, full static recrystallization occurs at temperatures above 975 ºC.

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