Provided for non-commercial research and education use.
Not for reproduction, distribution or commercial use.

This article appeared in a journal published by Elsevier. The attached copy is furnished to the author for internal non-commercial research and education use, including for instruction at the authors institution and sharing with colleagues.

Other uses, including reproduction and distribution, or selling or licensing copies, or posting to personal, institutional or third party websites are prohibited.

In most cases authors are permitted to post their version of the article (e.g. in Word or Tex form) to their personal website or institutional repository. Authors requiring further information regarding Elsevier's archiving and manuscript policies are encouraged to visit:

http://www.elsevier.com/copyright

Author's personal copy

Journal of Alloys and Compounds 490 (2010) 572–575

Contents lists available at ScienceDirect

Journal of Alloys and Compounds

journal homepage: www.elsevier.com/locate/jallcom

Investigation on the effects of hot forging parameters on the austenite grain size of vanadium microalloyed forging steel (30MSV6)

A. Babakhani [a], S.M.R. Ziaei [b], A.R. Kiani-Rashid [a,*]

[a] *Materials Science Engineering Department, Ferdowsi University of Mashhad, P.O. Box: 91775-1111, Mashhad, Iran*
[b] *Materials Science Engineering Department, Sharif University of Technology, P.O. Box: 11365-9466, Tehran 14584, Iran*

ARTICLE INFO

Article history:
Received 1 September 2009
Received in revised form 1 October 2009
Accepted 11 October 2009
Available online 21 October 2009

Keywords:
Microstructure
Grain boundaries
High temperature alloys
Metallography

ABSTRACT

It is known that the thermomechanical processing is one of the most important techniques for improving quality and mechanical properties of microalloyed steels. In this paper, the main parameters of hot forging (preheat temperature, strain and post-forging cooling rate) on the primary austenite grain size of vanadium microalloyed steel (30MSV6) were studied. From this investigation, it was found that increasing preheat temperature from 1150 °C to 1300 °C will result in a decrease in grain size number. Furthermore, it has shown that as the strain increases, the austenite grain size number increases, as is evident for the two cooling rates of 2.5 °C/s and 1.5 °C/s for primary austenite. Finally, it can be concluded that a verity of microstructures in microalloyed steels can be obtained depending on the deformation temperature and cooling rate.

© 2009 Elsevier B.V. All rights reserved.

1. Introduction

Quality of forged steels strongly depends on dominating mechanism in the hot forging process [1]. In recent years, microalloyed medium carbon forging steels have gained acceptance as a replacement for the conventional quenched and tempered (Q–T) grades in automotive and some other applications. The driving force for the use of MA steels is cost reduction due to elimination of post-forging heat treatment, straightening, stress relieving, and improved machinability [2,3].

Although, microalloyed steels have the same level of strength as compared to the quenched and tempered steels, their toughness is lower. To improve the toughness, carbon level of microalloyed steel has been reduced over the years and the decrease in strength as the consequence of this is compensated by microalloying with vanadium using its precipitation hardening effect [4]. Further increase of toughness can be achieved by microstructural control during the thermomechanical processing [5].

Microalloyed steels can be divided into six groups: (1) niobium microalloyed steels, (2) vanadium–niobium microalloyed steels, (3) vanadium–molybdenum microalloyed steels, (4) vanadium–nitrogen microalloyed steels, (5) titanium microalloyed steels, and (6) titanium–niobium microalloyed steels.

A variety of microstructures in microalloyed steels can be obtained depending on the deformation temperature, degree of upset, cooling rate and the chemical composition [6].

Each of the microstructure variables such as austenite grain size number is highly influenced by the composition of the MA steels, the forging parameters such as preheat temperature, strain (or degree of upset) utilized and the post-forging cooling rate [7]. The strength and toughness of MA steels can be enhanced by thermomechanical processing through grain refinement, strain induced precipitation of fine microalloying carbide and carbonitride particles [8,9].

Some advantages and disadvantages of microalloyed steels in comparison with heat-treated steels are: cost saving benefits in machining, improved fatigue characteristics and weldability.

In the present study, the evolution of the austenite grain size in microalloyed forging steel (30MSV6) with vanadium was studied as a function of preheat temperature, strain and post-forging cooling rate. The results revealed a significant effect of these parameters on grain size. We also discuss the austenite grain size of the vanadium microalloyed forging steel under various forging conditions.

2. Experimental procedure

In this paper, the main parameters of hot forging (preheat temperature, strain or degree of upset and post-forging cooling rate) upon primary austenite grain size of vanadium microalloyed steel (30MSV6) were investigated. The chemical composition of this steel is listed in Table 1. The material was supplied by the Iran Alloy Steels Company. It had ferritic and pearlitic microstructure.

The steel was supplied in the form of round bar billets of 52-mm diameter and 130-mm length. The specimens were divided into two groups and solutionized at 1150 °C and 1300 °C for 2 min in a preheated forging induction furnace. The experiments were performed with a 1000 tonnes mechanical press.

* Corresponding author. Tel.: +98 511 7683199; fax: +98 511 8763305.
E-mail addresses: fkiana@yahoo.com, kianirashid@gmail.com (A.R. Kiani-Rashid).

0925-8388/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.jallcom.2009.10.083

Author's personal copy

Table 1
Composition of microalloyed vanadium steel (wt.%).

C	Si	Mn	Ni	Cr	Mo	V	Cu	Ti	P	S	Fe
0.3	0.56	1.49	0.08	0.22	0.01	0.11	0.19	0.017	0.013	0.078	balance

The test specimens were forged at constant strain rate of 0.1 s^{-1} at two upset temperatures of 1150 °C and 1300 °C. Forging was carried out to thickness reductions of 30% and 45% strain induced, respectively. Cooling rate was followed by air cooling at the rates of 1.5 °C/s and 2.5 °C/s. The specimens were polished according to standard metallographic methods for austenite grain size measurement and optical microscopy observations. The austenite grain size was measured with Aquinto AG image analysis software. Optical microscopy was carried out with Nikon microscope model ME600.

Table 2 shows four different thermomechanical statues used for investigation on the effects of forging parameters.

In order to precisely control the cooling rate of specimens and to keep homogenous microstructure during cooling, a twin conveyor device by the authors was used.

The cooling rates were calculated by measuring the temperature of specimens at two locations, namely after coming out of furnace and conveyor using a calibrated pyrometer. The temperature of the billets during deformation was also recorded by the same pyrometer.

Table 2
Twelve different thermomechanical statues used for investigation on the effects of forging parameters.

Experiment statues	Preheat temperature (°C)	Strain (%)	Cooling rate (°C/s)
A_1	1150	0	1.5
A_2	1150	30	1.5
A_3	1150	45	1.5
B_1	1150	0	2.5
B_2	1150	30	2.5
B_3	1150	45	2.5
C_1	1300	0	1.5
C_2	1300	30	1.5
C_3	1300	45	1.5
D_1	1300	0	2.5
D_2	1300	30	2.5
D_3	1300	45	2.5

3. Results and discussion

Fig. 1 shows the austenite grain size of the microalloyed steel under various forging conditions. As can be seen, increasing the

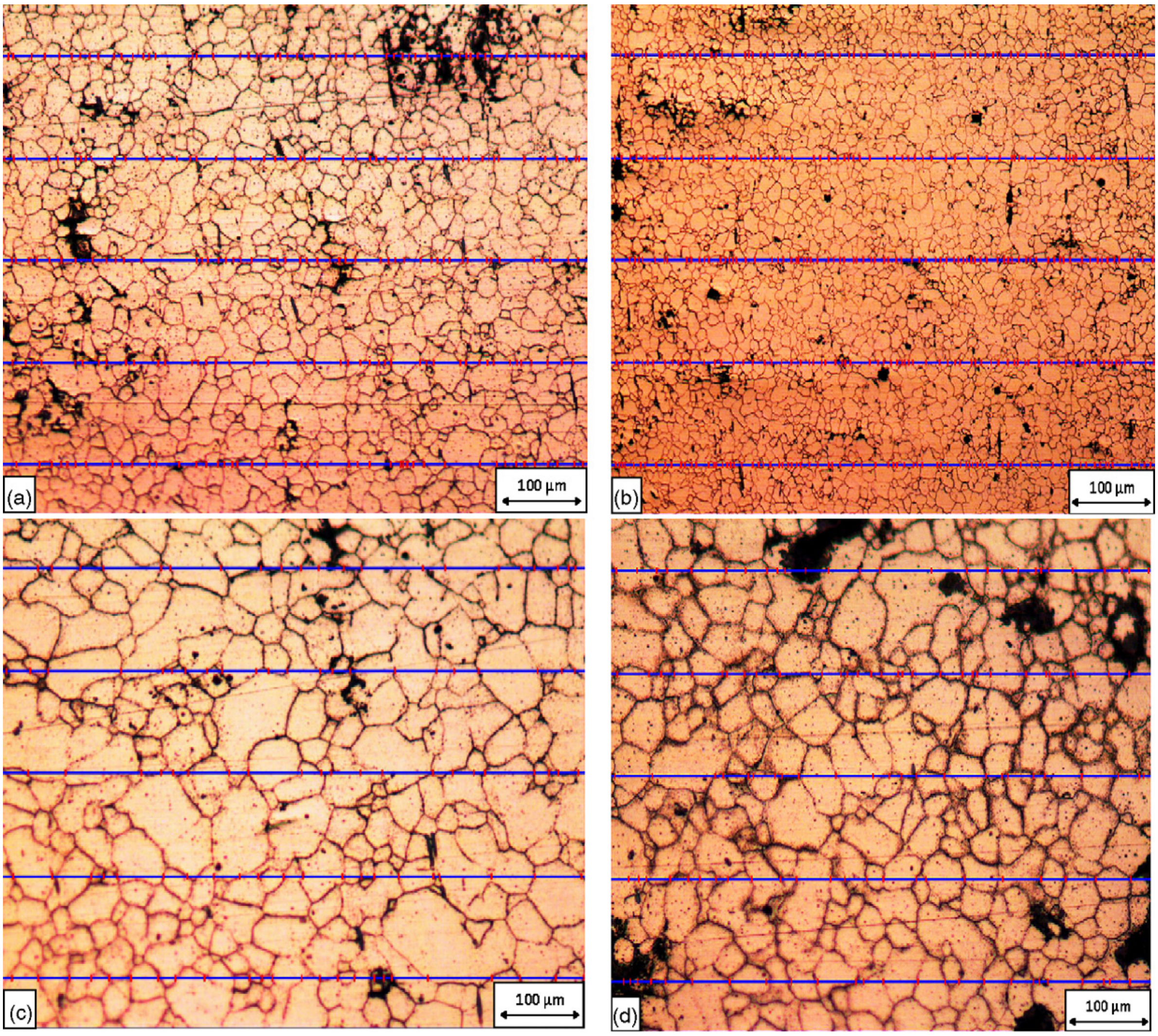

Fig. 1. Austenite grain size of specimens at different thermomechanical conditions indexed according to Table 2.

Author's personal copy

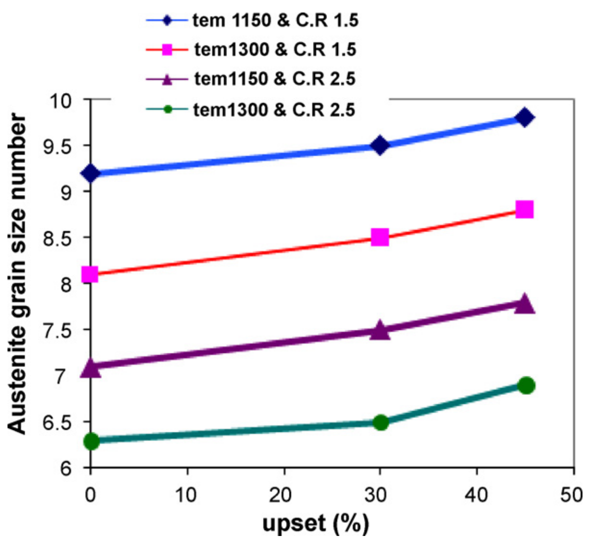

Fig. 2. Effect of forging parameters (deformation temperature, % upset and cooling rate) on the austenite grain size number.

cooling rate after forging at 1150 °C leads to finer austenite grain sizes. These effects are generally associated with the influence of post-forging cooling rate on austenite grain size.

Increasing deformation temperature at 0% upset leads to decrease in austenite grain size number, which is due to more growth of primary austenite grains at higher temperatures.

This phenomenon also holds for 30% and 40% upsets. Hot working at higher temperature causes the austenite grains to grow more [10]. This is a common phenomenon due to higher mobility of atoms at higher temperatures, and it is obvious that with increasing deformation temperature, the mobility of grain boundaries lead to further growth of large grains and elimination of finer grains.

The important point here is increasing the amount of strain during forging. The results revealed a significant effect of hot forging parameters on the austenitic grain growth control. The grain size number of primary austenite increases when the cooling rate is increased from 1.5 °C/s to 2.5 °C/s. This is due to the decreased time of diffusion from one grain to another at the higher cooling rates. At high cooling rates there is not enough time for diffusion, and therefore no time for austenite grains to grow.

In this study the quantitative analysis was performed by image analyzer software to measure the austenite grain size number. The result is illustrated in Table 2. As can be seen, by decreasing the deformation temperature from 1300 °C to 1150 °C the austenite grain size number increased. As seen in Fig. 2, for samples with same cooling rates, decreasing the deformation temperature decreases the final austenite grain size. It is also observed that the microstructures of samples deformed at 1150°C are finer than those deformed at 1300 °C. Generally, decrease in the deformation temperature leads to a decrease in austenite grain size.

A microalloy addition of vanadium is frequently used for grain size control and/or precipitation hardening.

The effect of microalloy precipitate depends on the temperature at which it forms in relation to the transformation temperature of the steel [11]. Because of vanadium precipitating particles in these steels, recrystallization would be delayed and because these particles form at temperatures around 950 °C during cooling from austenite temperature, we can deduce that recrystallization temperature is higher than the temperature at which participates start to form [12].

Due to the interaction of solute and precipitated vanadium, austenite recrystallization can be delayed to such an extent that it will practically be absent below a certain temperature.

Dynamic recrystallization taking place during the hot forging is dominant when high strains are applied at temperatures in upper γ-range. The kinetics of recrystallization depends on the austenite state (grain size, chemical composition, etc.) and deformation parameters (temperature, strain and strain rate). Thus it determines final grain size of austenite.

The existence of fine vanadium precipitates will significantly aid in controlling the austenite grain size at high austenitising temperatures during hot forging. The base steel with addition of only vanadium will form finer vanadium carbonitrides that are more effective in grain size stabilization [1,13–15].

Conventional forging is performed at temperatures above 1100 °C. However, vanadium is most effective in refining the microstructure when delaying the austenite recrystallization. Vanadium was added because of its precipitation hardening capability, with a view to improve the toughness properties. The vanadium precipitates formed would control the austenitic grain growth and the recrystallized austenitic grain size [15]. Thereby, these precipitates (vanadium carbonitrides and nitrides) reduce the ferrite–pearlite grain size obtained by decomposition of the austenite during cooling at rates close to air cooling [16].

4. Conclusions

(1) The results indicated that vanadium microalloyed steel is capable of exerting a significant control on austenite grain growth at different conditions.
(2) In the present study, the influence of thermomechanical processing parameters on the microstructure is investigated. The variation of primary austenite grain size as a function of forging conditions was followed by optical microscopy.
(3) The metallography results indicated that increasing the deformation temperature, leads to decrease in the austenite grain size number and the grain size number of primary austenite increases when the cooling rate is increased from 1.5 °C/s to 2.5 °C/s.
(4) With increasing the amount of strain during forging, the primary austenite grain size number to some extent.
(5) The higher the cooling rate, the lower the temperature at which the precipitates form.

Acknowledgements

The authors are grateful to College of Engineering, Ferdowsi University of Mashhad for provision of laboratory facilities. We would also like to express our sincere thanks to the Research Council of Ferdowsi University of Mashhad for supporting this work.

References

[1] A.J. DeArdo, Ironmaking Steelmaking 28 (2) (2001) 138–144.
[2] ASM Hand Book, Properties and Selection: Irons, Steels, and High Performance Alloys, vol. 1, ASM International, 1999.
[3] D. Rasouli, Sh. Khameneh Asl, A. Akbarzadeh, G.H. Daneshi, J. Mater. Process Technol. 206 (1–3) (2008) 92–98.
[4] M. Jahazi, B. Eghbali, J. Mater. Process Technol. 113 (1–3) (2001) 594–598.
[5] S. Gunduz, R.C. Cochrane, Mater. Des. 6 (6) (2005) 486–492.
[6] J.H. Woodhead, G. Krauss, S.K. Banerji, Fundamentals of Microalloyed Forging Steels, TMS, Warrendale, PA, 1986, pp. 3–17.
[7] S. Gunduz, R. Kacar, H.S. Soykan, Tribol. Int. 41 (2008) 348–355.
[8] C.A.C. Imbert, H.J. McQueen, Mater. Sci. Eng. A313 (2001) 104–116.
[9] D.J. Naylor, Mater. Sci. Forum 284–286 (1998) 83–94.
[10] G. Nussbaum, J. Richter, A. Gueth, A. Koethe, R. Kaspar, I. Gonzalez-Baquet, Mater. Sci. Forum 284–286 (1998) 443–450.
[11] W.J. Liu, J.J. Jonas, Metall. Trans. A 20 (1989) 689.

Author's personal copy

[12] J.M. Rodriguez-Ibabe, Mater. Sci. Forum 284–286 (1998) 51–62.
[13] M.A. Linaza, J.L. Romero, J.M. Rodriguez-Ibabe, J.J. Urcola, Scripta Metall. Mater. 29 (1993) 1217–1222.
[14] R.M.K. Honeycomber, H.K.D.H. Bhadeshia, Steels, Microstructure and Properties, 2nd ed., Arnold, London, 1995, p. 189.
[15] F. Penalba, C. Garcia De Andres, M. Carsi, F. Zapirain, J. Mater. Sci. 31 (1996) 3847–3852.
[16] R.W.K. Honeycomber, HSLA Steels: Metallurgy and Applications, ASM International, 1986, pp. 243–250.