Influence of Initial Microstructure on Hot Deformation Behavior of Duplex Stainless Steels

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ABSTRACT

In this research the effect of initial microstructure on hot deformation behavior in terms of Ferrite-to-Austenite ratios is studied. Two types of stainless steels C1 and C2 were homogenizing heat-treated and deformed under hot compression examinations at temperatures 900ºC and 1100ºC at strain rate of $0.1s^{-1}$. The results showed that the flow stress levels of specimens are strongly related to deformation parameters and initial microstructures of steels. Moreover, during cooling from 1350ºC to the deformation temperature, flow stress level increased for both samples because of increment in austenite content.

1. Introduction

Duplex stainless steels are well developed in marine, chemical and petrochemical industries due to good corrosion resistance properties. Proper chemical composition, mechanical properties and corrosion resistance, are the main reasons for widespread application of these steels [1, 2]. These steels show higher strength and higher toughness than common austenitic and ferritic steels, respectively. Stress corrosion cracking, hydrogen embrittlement and inter-granular corrosion resistance in addition with good weldability are some other benefits of them [3, 4].

At the initial steps of hot deformation process, the strain concentrates on ferrite phase and there is a balance between work hardening and dynamic recovery. While the strain is increased, deformation concentration shifts on austenite phase and work hardening becomes the only dominant mechanism. In this situation by increasing the strain, recrystallization starts in austenite phase and decreases the flow stress level simultaneously. Restoration mechanism in ferritic-austenitic duplex stainless steels consists of dynamic recovery and dynamic recrystallization phenomena [5-8].

There are a few researches on the relationship between microstructure and hot deformation behavior, when deformation condition and chemical composition are changing. In this study, the effect of initial microstructure on hot deformation behavior is investigated.

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2. Experimental Procedure

In this study, two types of ac-cast duplex stainless steels coded C1 and C2 are investigated. Chemical compositions of them are listed in Table 1.

Table1 Chemical Compositions of Materials.

Steel	%C	%Cr	%Ni	%Mo	%Si	%Mn
C1	0.08	27.90	3.39	1.59	0.4	1.12
C2	0.07	20.76	6.4	2.8	0.25	0.67

Cylindrical compression specimens of 10mm in initial diameter and 15mm in height were machined from casted slabs. In order to homogenize the microstructures, all the specimens are held at a temperature of about 1250ºC for 2 h before hot deformation tests. To evaluate the austenite volume fraction effects on hot deformation behavior of duplex stainless steels, two different heat treatment cycles, on-heating and on-cooling, are exerted on specimens (Fig. 1). A Z250 Zwick/Roe uniaxial hot compression machine equipped with a resistance furnace is used for applying the tests.

In on-heating cycle, specimens were preheated over the temperature range of 900ºC to 1100ºC for 5 min and then hot compression test was carried out at a constant strain rate of $0.1s^{-1}$. In on-cooling cycle, specimens were held at 1350ºC for 20min at first and then cooled down to the deformation temperature and held 1min, then hot compression test was performed at strain rate of $0.1s^{-1}$.

In order to exert strain rate of $0.1s^{-1}$ the constant velocity of machine's hydraulic ram was calculated 63mm/min according to equation 1.

$$v = \frac{\dot{\varepsilon}\Delta l}{\ln l/l_0} \qquad (1)$$

Where v, $\dot{\varepsilon}$, Δl, l and l0 denote velocity of machine's hydraulic ram, strain rate and variation of specimen's height during the deformation, final height and primary height of specimens, respectively.

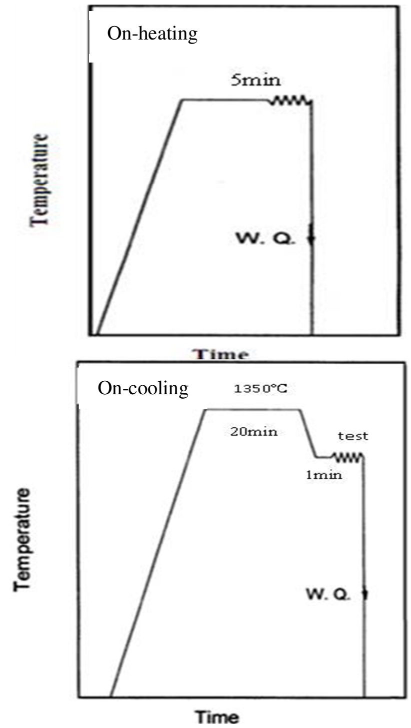

Fig.1. Schematic of heat treatment cycles.

Moreover, when hot deformation was finished, specimens were water quenched for less than 5 sec and were cut longitudinally for microstructural investigations. After preparation and etching of specimens in HCl and potassium metabisulfite, $K_2S_2O_5$, microstructures were studied by employing CLEMEX software.

3. Results and Discussion

Microstructural investigations of specimens after homogenizing heat treatment showed different volume fractions of two austenite and ferrite phases (Fig. 2). Austenite volume fraction of steel C2 at room temperature is higher than steel C1, as shown in Fig. 2. It should be noted that ferrite-to-austenite ratio varies with variation of temperature [6].

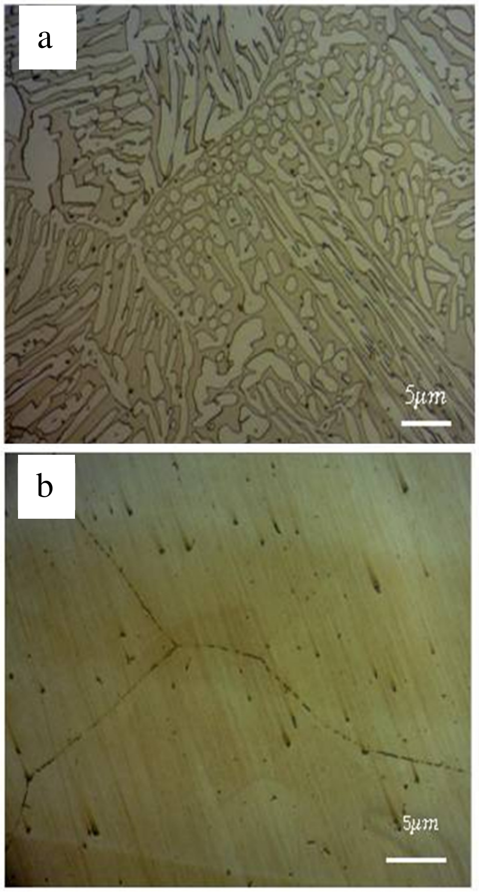

Fig.2. Microstructure of homogenized samples (a) C2 (The light phase is austenite and the matrix is ferrite) (b) C1 (Essentially ferritic microstructure).

Austenite volume fraction variations for different temperatures after applying on-heating and on-cooling heat treatment cycles are presented in Fig. 3. According to some other investigations done on these two types of steels [9], strain rate sensitivity, m, for both steels are calculated by utilizing hot deformation test results of on-cooling cycle at strain rates of $0.1s^{-1}$ and $0.001s^{-1}$. The amount of m depends on dislocations density. The higher the dislocation motion, the larger will be the amount of m [2]. Annihilation and rearrangement of dislocations at high temperatures i.e. dynamic recovery, DRV, is more convenient in ferrite phase. In steel C1, the magnitude of m declines with increase of temperature which is in accordance with on-cooling curve in Fig.3 science volume fraction of austenite increases as the temperature rises. In on-cooling cycle for steel C2, as temperature went up, volume fraction of austenite decreased (Fig. 3) and the magnitude of m increased. The magnitude of m for steel C1 is more than steel C2 at all temperatures; because austenite volume fraction of steel C1 is less than steel C2.

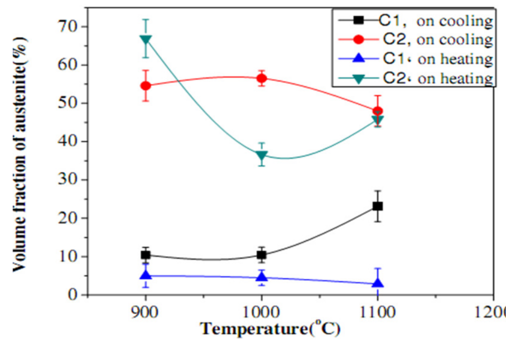

Fig.3. Dependence of austenite volume fraction on deformation temperature for cycles 1 and 2.

True stress-strain curves of steels C1 and C2 which are resumed from hot deformation tests at 900ºC and 1100ºC are presented in Fig. 4. As illustrated in Fig. 4a and 4b, flow stress level increases with plummet of hot deformation temperature. Moreover, as strain is increasing, flow stress increases and reaches a maximum value and then takes a steady state which shows that dynamic recovery phenomenon, DRV, (Fig. 4a and 4b) is occurring. It should be noted that flow stress level of deformed on-cooling specimens at 900ºC is higher than their on-heating cycles (compare Fig. 4a and 4b). In other words, for samples which are cooled from 1350ºC to hot deformation temperature (900ºC), flow stress level is higher than those held at hot deformation temperature. It is attributed to variations in volume fraction of austenite (Fig.3).True stress-strain curves yielded from hot deformation of steel C2 at different temperatures are illustrated in Fig. 4c and 4d. As shown in Fig. 4d, flow stress increases with increase of strain and reaches a maximum value; then takes a steady state which reveals the occurrence of dynamic recovery phenomenon. Also, flow stress level has decreased with increase of temperature. Changing the heat treatment process changes the microstructure and consequently changes hot deformation behavior. In hot deformation at 900ºC, increase of strain increases the flow stress to reach a maximum value and then decreases smoothly as represented in Fig. 4d. Decrease in flow stress after the peak stress is attributed to the dynamic recrystallization phenomenon, DRX.It can be seen that increase in temperature decreases flow stress level and so clearly elucidates a peak characterizing recrystallization on the graph and reveals occurrence of dynamic recrystallization phenomenon. It should be stated that flow stress levels for C2 specimens are higher than C1 specimens under the same condition, namely on-heating cycle. It is attributed to higher volume fraction of austenite in steel C2 (compare Fig. 4a and 4d). Therefore it is expected that dynamic recrystallization could be observed in graphs when a considerable mixture of ferrite and austenite phases exist in microstructure. According to graphs of Fig. 4, it can be interpreted that flow stress for steel C2 is higher than C1 anywhere. High ductility of steel C1 is caused by two factors: a) ease of dislocation annihilation and sub-boundary formation as a reason for rather low flow-stress and b) movement of high-angle boundaries which restraint crack formation in main boundaries. These cracks usually are created by grain boundary slip in triple point of austenite grain boundaries [10-12].Fig. 5 exhibits maximum stress content vs. temperature for steels C1 and C2. It is perceived that maximum stress and thus flow stress decreases dramatically with increase of temperatures. Flow stress level for steel C2 is higher than steel C1 which is a consequence of higher volume fraction of austenite in steel C2 than C1. On-cooling process offers higher strength than on-heating process for steel C1. As mentioned before, this stress variation could have been resulted from the presence of austenite particles in on-cooling cycle microstructures.

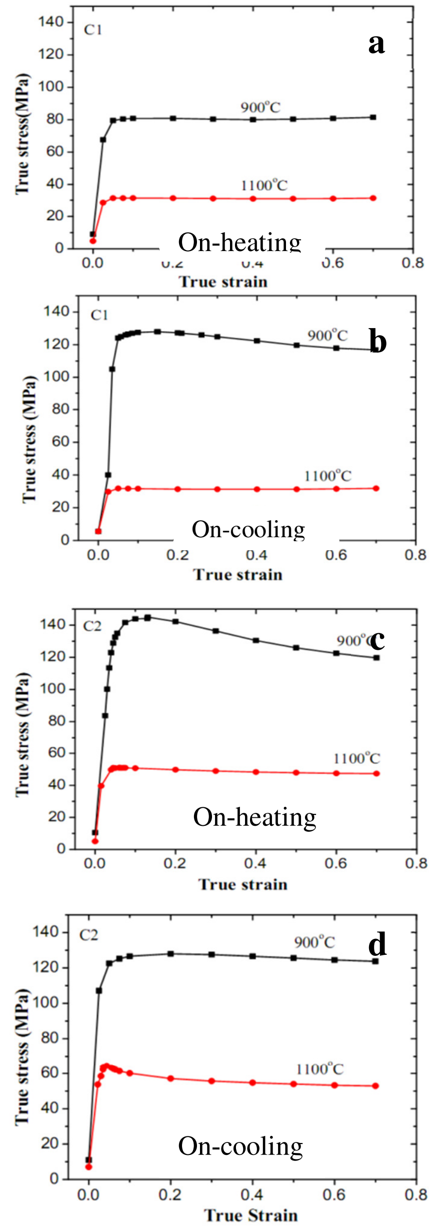

Fig.4. True stress-strain curves for steels C1 and C2 under different deformation condition withstrain rate of 0.1 sec^{-1}.

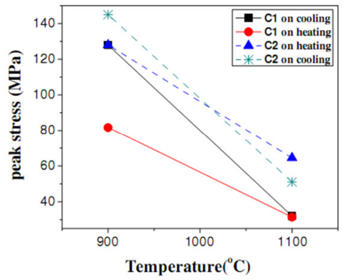

Fig.5. Dependence of the peak stress on deformation temperature for steels C1 and C2.

In order to evaluate the effect of thermo–mechanical parameters of microstructure, specimens are immediately quenched after hot deformation. Fig. 6 reveals microstructures of hot-deformed C1 specimens. According to Fig. 6, microstructure (at deformation temperature of 900ºC) consists of dispersed austenite particles in a ferrite matrix. Increase of deformation temperature to 1100ºC, leads to coarsening and increase in volume fraction of austenite phase. Finer ferrite grains are produced at this temperature than 900ºC (see Fig. 6a and 6b). Moreover, in higher deformation temperatures, carbide precipitates are formed in microstructure. Microstructures of specimens which are cooled from 1350ºC to the deformation temperature reveal an increase in austenite particles (compare Fig. 6a and 6c). Therefore, it can be inferred that heat treatment process as well as deformation temperature influence the austenite formation. In other words, austenite phase percentage rises by increase of deformation temperature. Also, increase in austenite particles content has increased flow stress level (Fig.5).

Fig. 7 shows microstructure of hot deformed C2 specimens. It can be seen that microstructures are composed of two phases, austenite and ferrite, which have more austenite content than C1 specimens. Microstructural images of these specimens cooled from 1350ºC to the deformation temperature illustrate thicker layers of austenite phase and a more packed microstructure, as well (compare Fig. 7a and 7b with 7c and 7d). It is concluded that the type of heat treatment process affects austenite volume fraction in specimen's microstructures.

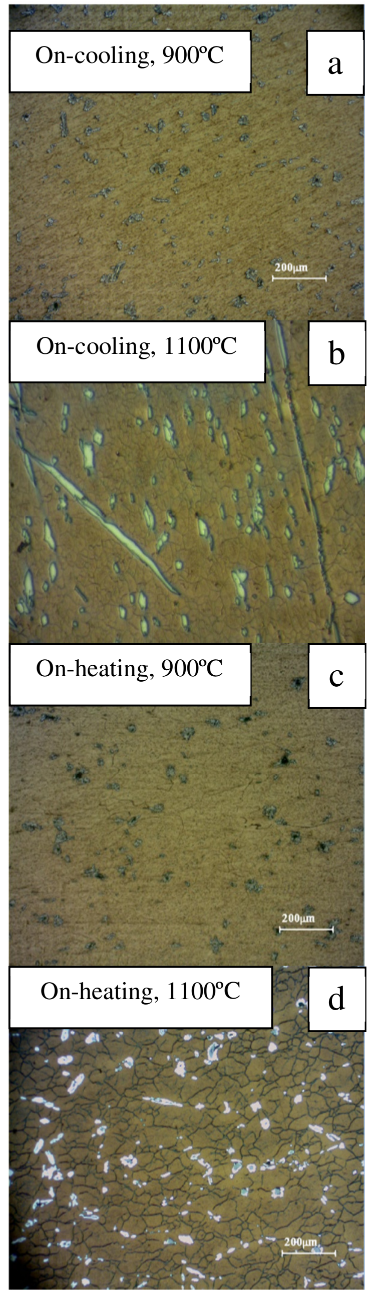

Fig.6. Microstructures of hot deformed steel C1 at 900°C and 1100°C.The dark phase is ferrite and the light one is austenite

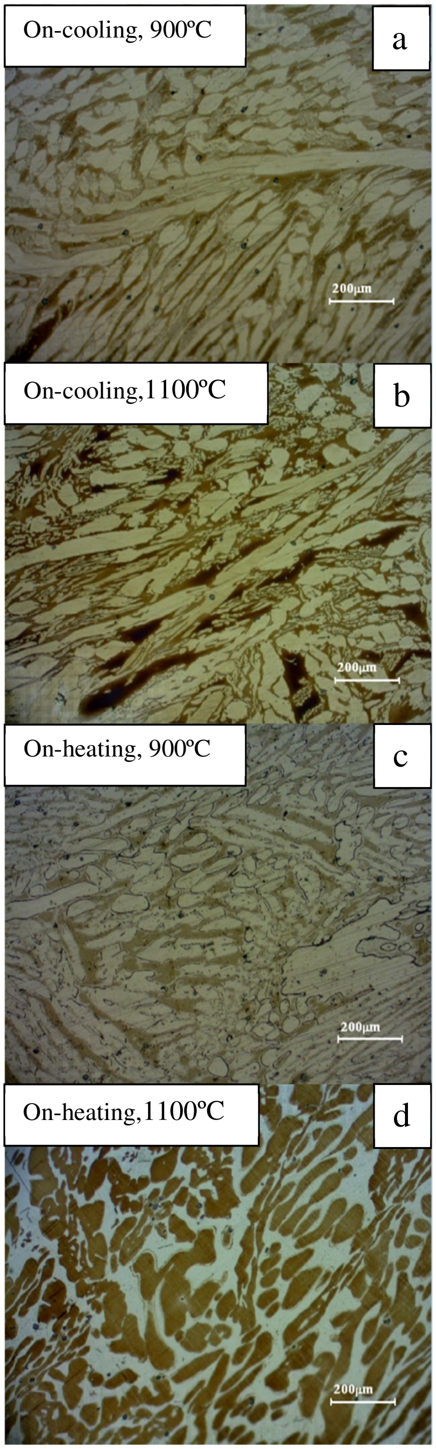

Fig.7. Microstructures of hot deformed steel C2 at 900 °C and 1100°C.The dark phase is ferrite and the light one is austenite.

In addition, increase of deformation temperature (1100ºC) leads to negligible increment of austenite phase content. It can be seen from Fig. 5 that differences in flow stress levels for both on-heating and on-cooling cycles are smaller for C2 specimens than C1.

4. Conclusions

Increase in austenite phase content, rises flow stress level significantly.Flow stress level for specimens cooled from 1350ºC to deformation temperature is higher because of their higher austenite volume fraction. In fact, flow stress levels for on-cooling cycles are higher than on-heating cycles.

Furthermore, it can be deduced that heat treatment process as well as deformation temperature influence the austenite formation. In other words, the use of on-cooling cycle results in more austenite content than on-heating cycle. It can be used to choose either the suitable temperature or suitable type of heat treatment for achievement of certain austenite volume fraction in microstructure.

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