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Research Article

Mechanism of Edge Crack Formation in AISI304L Steel During Hot Rolling

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ABSTRACT

In this study, the effect of delta ferrite formation and segregation of alloying elements on the mechanism of the edge cracking on the surface of AISI304L stainless steel during hot rolling in Iran Alloy Steel Company was evaluated. For this purpose, scanning electron microscopy (SEM) with two detectors, SE and BSE, and EDX analysis were used to examine the areas around the crack. The results were shown that the tendency to create edge cracks during hot rolling increases with enhancement delta ferrite content and the mechanism of crack growth is along the delta ferrite and the delta ferrite/ austenite interface. SEM studies of the crack-containing specimens showed the number of micro-cracks in the areas around the main crack and the presence of worm-shaped delta ferrites and delta ferrite islands in the austenitic matrix. In addition, the segregation of the copper element also plays an important role in creating cracks in the surface of AISI304L stainless steel ingots during hot rolling.

1. Introduction

Hot rolling is a common step in manufacturing the steel products. In general, austenitic stainless steels (ASS) are substantially harder during hot-rolling than either ferritic or mild steels. The high strength of these steels in hot working conditions often requires the use of high rolling temperatures to avoid excessive mill loading. In some cases, there innately low hot-ductility may lead to edge cracking and other defects. There are many factors that can affect the hot ductility of steels, such as: temperature, strain rate, composition, grain size, precipitates, non-metallic inclusions and previous thermal and mechanical treatments [1].

The microstructure of austenitic stainless steels usually consists of delta ferrite and austenite phases. Studies have shown that the delta ferrite phase may be detrimental to the high-temperature workability of these steels. Therefore, for some applications, the cast steel is reheated to and held at annealing temperatures to dissolve the delta ferrite phase as much as possible. However, this procedure may result in grain growth, and hence the formation of delta ferrite may be controlled during casting of steels to decrease its volume fraction as much as possible in the microstructure [2, 3].

Numerous studies have investigated the formation of delta ferrite during solidification in austenitic stainless steels [4, 5]. However, only a few researchers reported the formation of delta ferrite due to hot deformation in austenitic stainless steels [6,7]. Venugopal et al. Observed

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newly formed delta ferrite phase in AISI 304L austenitic stainless steels deformed at 1200°C and strain rate of 100 s^{-1}, showing that the austenite to ferrite transformation occurred in the region of intense shear [7]. Sundararaman et al. Also found delta ferrite formed after hot deformation of AISI 304L at 1200°C and strain rate of 100s^{-1} deformation conditions. Their results suggest that the percentage of the ferrite phase depends on deformation condition. They concluded that defects such as dislocations produced under various deformation conditions facilitated the nucleation and growth of delta ferrite [6].

Results Wang et al. Showed that the hot workability of 18Mn18Cr0.5N steel gradually decreased with increasing preheating temperature between 1100 and 1200°C, and quickly deteriorated up to 1250°C. Above 1200°C, delta ferrite particles appeared in 18Mn18Cr0.5N steel, which promoted cavity coalescence on grain boundary and accelerated surface crack formation during the hot working process [8]. Shi et al. Attributed the cracking in austenitic stainless steels to the lower strength of delta ferrite (a quarter of austenite) and the more severe plastic deformation in delta ferrite than austenite [9].

An increase in deformation temperature and strain rate is believed to be the cause of the formation of higher amounts of delta ferrite in 304 and 304L stainless steel. It has been shown that the ratio between chromium equivalent and nickel equivalent (Creq/Nieq) affects the formation of delta ferrite during the solidification of stainless steels. Since there is still a concern about cracking of austenitic stainless steels during hot rolling in the industry and Iran Alloy Steel Company, in the present study, the mechanism of cracking in austenitic 304L stainless steel due to temperature increase above 1250°C was investigated [10].

2. Materials and methods

Ingots with an average weight of 2 tons are acquired to make stainless steel billets. Then ingots are reheated during 2 hours up to temperatures around 1300 °C in soaking pit and are transformed from a 400x400 section to a 150x150 billet during 19 passes in heavy rolling. To investigate the mechanism of cracking in 2 ton AISI304L steel ingots during hot rolling, samples were taken from the crack site. Table 1. presents the analysis of the samples. After polishing, the samples were electropolished with 10 wt% oxalic acid solution for 3 minutes. The FEIESEM QUANTA 200 electron microscope with two detectors, SE and BSE, was used to apply 10 microns of gold coating to perform SEM imaging of the specimens. The US-made EDX EDAX Silicon Drift 2017 analyzer examined the point and linear EDX analysis of the target areas.

3. Results and discussions

The presence of surface and edge cracks is one of the problems that have recently been created during the hot rolling of 304L stainless steel in Iran Alloy Steel Company (Fig. 1.). In order to study the exact crack-forming mechanism in the samples, a detailed study of SEM and EDX was carried out.

The SEM image of the crack-containing specimens in Fig. 2. shows the number of micro-cracks in the areas around the main crack and the presence of worm-shaped delta ferrites and delta ferrite islands in the austenitic matrix. Fig. 3. shows well the accumulation of delta ferrites in the areas around the edge crack compared to the non-crack areas. This could be due to an increase in temperature or the time it takes for the ingots to be placed in the soaking pit or the strain rate applied during hot rolling.

Table 1. Chemical composition (weight percentage) of AISI 304L steel produced by Iran Alloy Steel Company.

Element	C	Ni	Cr	Cu	Si	Al
%wt	0.02	0.97	18.99	0.29	0.46	0.007

Fig. 1. Edge cracks created during hot rolling of AISI304L steel.

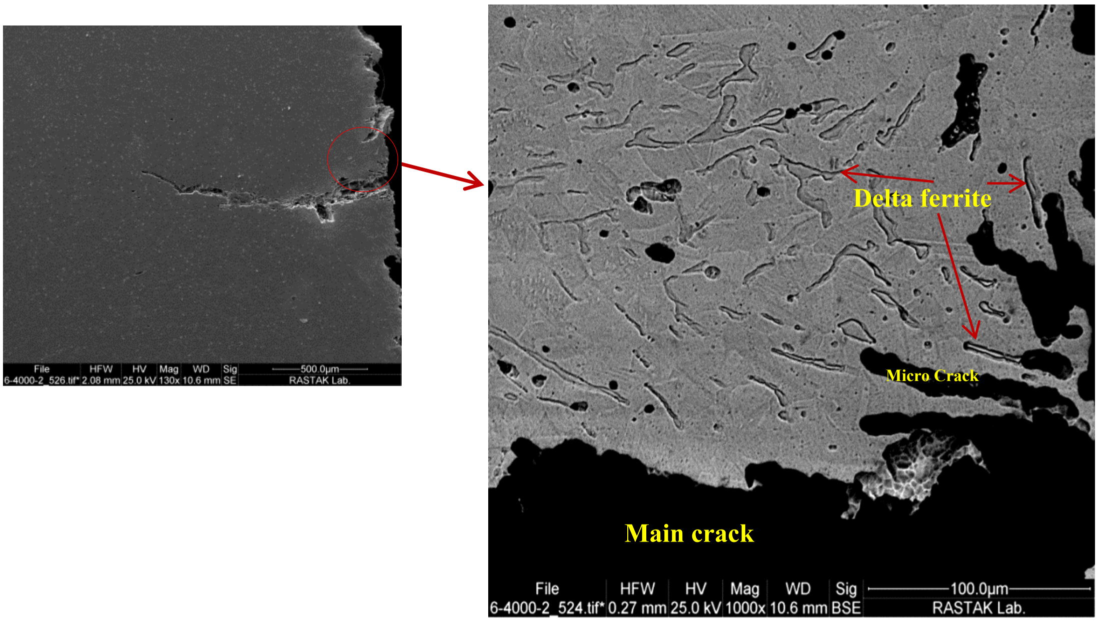

Fig. 2. Edge cracks created during hot rolling of AISI304L steel.

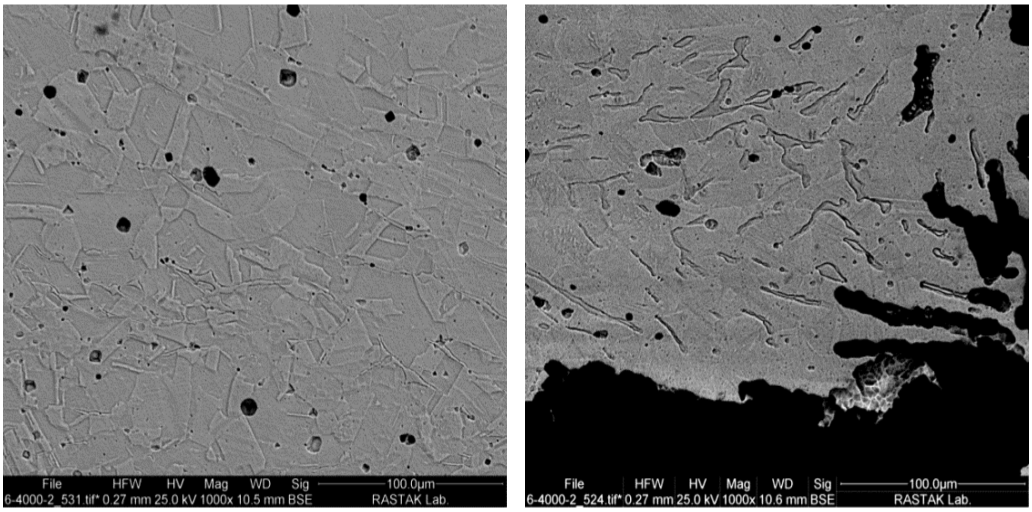

Fig. 3. Comparison of the presence of delta ferrite in cracked and non-cracked areas.

Fig. 4. shows the point EDX analysis near the cracks and along them, the segregation of ferrite stabilizers, especially chromium and silicon, and the reduction of austenite stabilizers such as nickel. The main reason for the segregation of ferrite stabilizers in localised areas is the structural heterogeneity of 304L ingots. A band of delta ferrite is formed due to the chemical composition of this segregation.

The linear EDX analysis of Fig. 5. (line AB) of the 304L samples demonstrates that the crack area has been enriched with chromium and nickel, with a decrease in nickel. Considering that in some points of the linear analysis, the amount of chromium has increased and the amount of nickel has decreased, this indicates the presence of delta ferrite in the areas around the crack [11]. The increase in ferrite delta in areas close to the ingot surface can be due to the increase in temperature or preheating time in the soaking pit. Therefore, it seems that increasing the temperature of the surface, especially the edges, leads to an increase in the formation of delta ferrite at the edges. These results ultimately show that delta ferrite plays a major role in crack formation [2]. The hot working capacity of 304L steel is greatly impacted by the higher fraction of delta ferrite, as it is well-established. The difference in deformation of both phases is supported by the high concentration of dislocations in the vicinity of the austenite/ferrite interface. It is generally agreed that such inhomogeneity in the microstructure may cause the generation of cavities at the austenite/ferrite interface which, in turn, may contribute to the crack's origin.

Point	Cr (%wt)	Ni (%wt)	Al (%wt)	Si (%wt)
1 (delta ferrite)	23.44	4.12	1.25	1.48
2 (delta ferrite)	25.12	3.58	0.36	0.87
3 (Austenitic matrix)	18.15	8.44	0.38	0.79
4 (delta ferrite)	24.46	3.65	0.32	0.9
5 (Austenitic matrix)	18.24	7.64	0.36	0.77
6 (delta ferrite)	23.52	3.83	1.51	1.65
7 (Austenitic matrix)	18.12	8.41	0.33	0.74

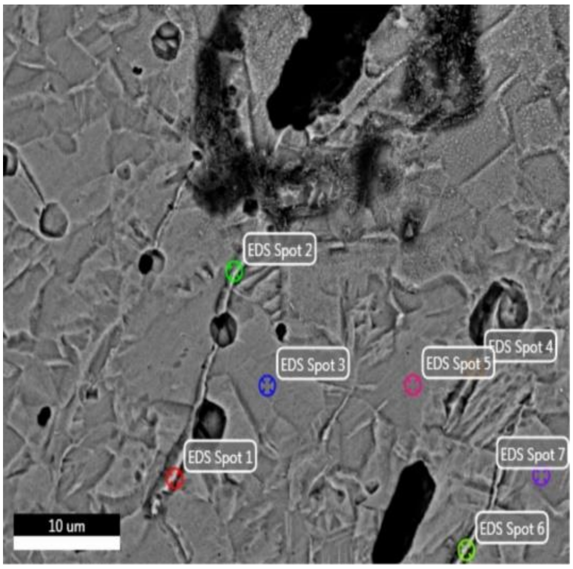

Fig. 4. Spot EDX analysis in areas around the crack.

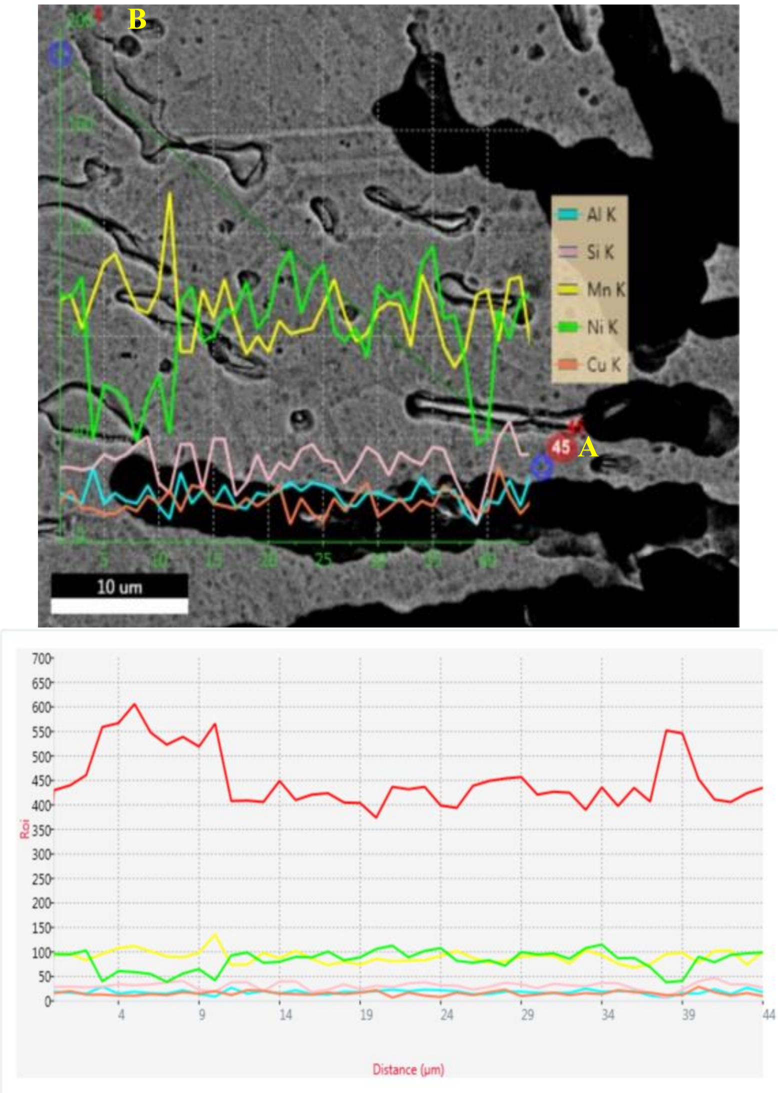

Fig. 5. Linear EDX analysis in the areas around the crack.

Furthermore, the EDX analysis of copper element points in certain 304L sample areas (Fig. 6.) reveals copper element segregation in crack areas. Copper can create a eutectic melt and cause grain boundary wettability. As a result, it reduces the grain strength and creates cracks during hot rolling by the axial flow [13].

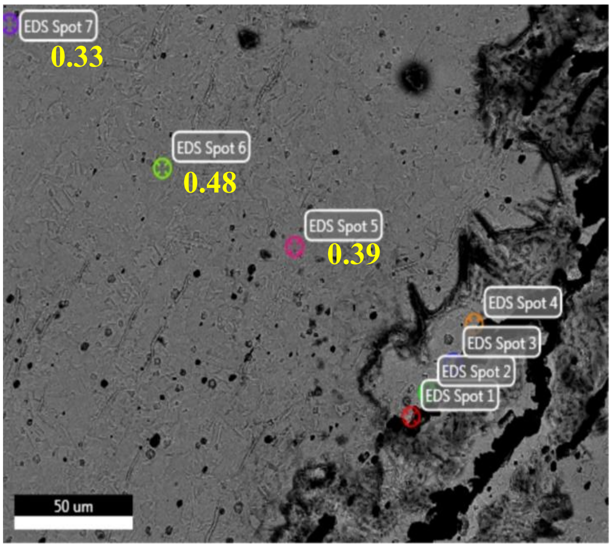

Fig. 6. Copper changes from close areas containing cracks to the center of the sample.

4. Conclusions

In this study, the effect of delta ferrite formation and segregation of alloying elements on the mechanism of edge cracking on the surface of AISI304L stainless steel during hot rolling was investigated. The main results obtained are:

- The probability of edge cracking in 304L austenitic stainless steel increases with a local increase of delta ferrite during hot rolling, and the mechanism of crack formation and expansion is a long delta ferrites.
- Segregation of ferrite alloy elements such as chromium and silicon occurs in areas containing delta ferrite, which confirms the formation of delta ferrite.
- A decrease in grain strength is a factor in cracking during hot rolling due to a local increase in copper in 304L austenitic stainless steels.

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