Influence of Inclusions on Impact Properties of J55 Steel

Hai-bo LI[1], Dong-wei ZHAO[1], Guo-sen ZHU[1], Chun-lin BAO[1], Jian YANG[2]

(1. Strips Technology Deparment, Shougang Research Institute of Technology, Beijing 100041, China; 2. Technical Quality Department, Heibei Shougang Qian'an Iron & Steel Co., Ltd., Qian'an 064404, Hebei, China)

Abstract: J55 steels are mainly used in the field of petroleum casing due to their excellent mechanical properties. Microstructure of J55 can improve its impact properties without losing strength. The characteristics of MnS inclusions including composition, morphology, size, mumber and area with different S content and Ca/S ratio in plates were studied utilizing SEM-EDS (scanning electron microscopy-energy dispersive spectrometry) and ASPEX. The effects of inclusions characteristics and molten steel compositions on impact properties were also investigated. The results demonstrate that inclusions affecting impact properties are mainly massive string typed MnS, especially those with size larger than 90 μm. Moreover, the number density and area density of MnS inclusions also have effect on the impact properties. The impact properties of steel are obviously improved by controlling S content to less than 0.004 0 mass% or Ca/S ratio more than 0.5 in plates, which ensures that the generation of larger size MnS inclusions is effectively inhibited and the number of MnS inclusions is reduced.

Key words: J55; MnS; Ca/S ratio; number density; area density; impact property

The oil pipe is often fixed with the wellbore and used for drilling operation with the well depth generally more than 2 000 m under very bad working conditions. According to the requirements of API SPEC 5CT standard, steel strips used for making pipe needs to have not only high tensile strength and yield strength, but also good impact properties. For example, API SPEC 5CT standard stipulates that the impact energy (−10 °C, lateral) should be more than 60 J. The impact properties of steel mainly depend on its microstructure determined by the chemical composition and heat treatment. Microstructural parameters of steels incorporate dislocation density, grain size as well as the volume fraction and size of second phase particles[1,2]. In general, carbon content of the steel is reduced to decrease the pearlite content and increase the ferrite content, further to improve the impact properties of steel[3]. Meanwhile, Mn content is often increased to make up for the loss of strength made by the decrease of carbon content. MnS inclusions in slab are easier to generate because of the increase of Mn content[4-6]. In order to suppress the precipitation of MnS inclusions, calcium treatment becomes one of the most effective measures[7-9]. At present, most studies concerning the impact properties mainly focuse on the composition and microstructure of steel[10-15], while the effect of inclusions on impact properties is rarely reported. In the present work, the effects of inclusions characteristics and molten steel compositions on impact properties were investigated and a good guide for further improving the impact properties of the steel was provided.

1 Experimental

Industrial trials were carried out at Qiangang Steel to study the effect of inclusions characteristics with different S contents and Ca/S ratios on the impact properties in J55 steel. The chemical composition and the corresponding impact properties of J55 steel are listed in Table 1.

Table 1 Chemical compositions and corresponding impact properties of steel samples

Sample	$w_{[C]}$/mass%	$w_{[Si]}$/mass%	$w_{[Mn]}$/mass%	$w_{[P]}$/mass%	$w_{[S]}$/mass%	$w_{[Ca]}$/mass%	$w_{[Ca]}/w_{[S]}$	Impact energy/J
1	0.189	0.177	1.11	0.010 5	0.001 8	0.001 7	0.809 5	73
2	0.182	0.186	1.10	0.009 7	0.002 6	0.002 4	0.923 1	78
3	0.187	0.182	1.12	0.016 6	0.004 3	0.001 4	0.323 7	59
4	0.175	0.173	1.11	0.015 9	0.005 9	0.001 5	0.246 4	51
5	0.155	0.164	1.06	0.013 4	0.007 3	0.001 2	0.164 4	29

During the experiment, the process to produce J55 is as follows: hot metal→ basic oxygen furnace (BOF)→ ladle furnace (LF)→continuous casting (CC)→hot rolling. The steelmaking process is a 210 t basic oxygen

Biography: Hai-bo LI, Doctor, Senior Engineer; **E-mail:** lhb2002@126.com

furnace. After tapping into a ladle, the steel is deslagged, and a new synthetic slag is added, as well as deoxidizer and the remaining alloys. When the steel obtains the apposite temperature and chemical composition, the ladle was transferred to the ladle furnace station. High basic and strong reducing refining slag was generated to reduce S content to less than 0.008 0 mass% and alloy was added to meet the composition requirements during LF refining. After LF refining, 400 m SiCa wire was fed into liquid steel with speed of 300 m/min. Finally, slab with thickness of 230 mm was produced by continuous casting and was hot rolled into strips with thickness of 10 mm. Steel samples were also obtained from hot rolled strips per heat. Chemical compositions of steel were analyzed with optical emission spectrometer. Inclusions in the center and side of steel samples were observed by JSM-6480LV scanning electron microscope (SEM) and ASPEX, respectively. Meanwhile, the impact energy of 130 samples with different S contents produced by the same process was detected to better analyze the effects of S content and Ca/S ratio on impact properties.

2 Results and Discussion

The chemical compositions and impact properties of the steel samples from hot rolled strips are listed in Table 1. As shown, the range of S content, Ca/S ratio and impact energy of steel samples is 0.001 8 mass%–0.007 3 mass%, 0.16–0.92 and 29–78 J, respectively. The types of inclusions observed by SEM are mainly string type MnS and near globular CaO-Al_2O_3-CaS composite inclusions, as shown in Fig. 1. The number density of MnS and CaO-Al_2O_3-CaS composite inclusions is listed in Table 2, where the number density of inclusion equals to the number of all inclusions divided by scanning area.

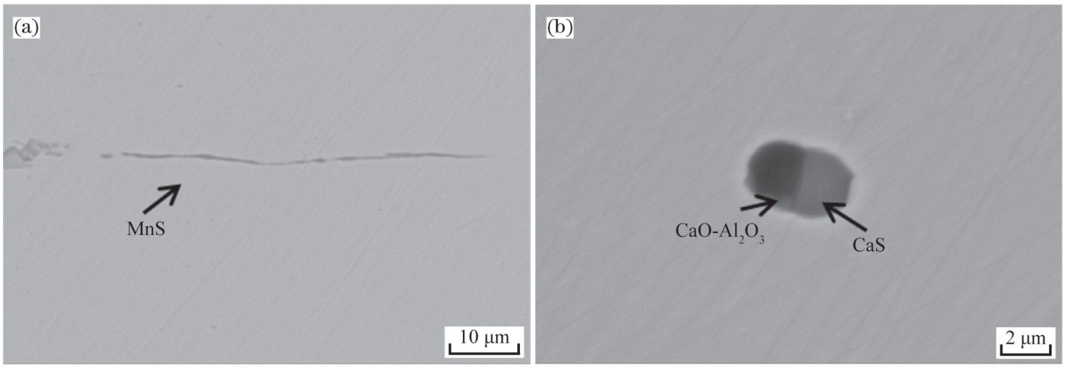

Fig. 1 Typical morphology of MnS (a) and CaO-Al_2O_3-CaS (b) composite inclusions in steel samples

Table 2 Number density of MnS and CaO-Al_2O_3-CaS composite inclusions at the center and edge of steel samples mm^{-2}

Sample	MnS inclusion		CaO-Al_2O_3-CaS composite inclusion	
	Center	Edge	Center	Edge
1	0.8	0.1	29.0	31.1
2	0.9	0.3	39.3	35.8
3	5.1	4.8	12.5	13.5
4	3.5	3.1	8.8	9.2
5	5.3	4.6	15.9	16.1

2.1 Effect of the type of inclusions on impact properties

It can be observed from Table 1 that samples 1 and 2 have good impact properties and their corresponding impact energy is 73 J and 78 J, respectively while samples 3, 4 and 5 have relatively poor properties and thier corresponding impact energy is 59 J, 51 J and 29 J, respectively. The number density of MnS and CaO-Al_2O_3-CaS composite inclusions at the center and edge of different steel sample is shown in Fig. 2. Fig. 2(a) shows that the number density of MnS inclusions in samples 1 and 2 is significantly less than samples 3, 4 and 5, which has a good relationship with their corresponding impact properties. In other words, the less the number density of MnS inclusions is, the better the steel samples impact properties are. Fig. 2(b) shows that there is no obvious relationship between the number density of CaO-Al_2O_3-CaS composite inclusions of steel samples and their corresponding impact energy, which indicates CaO-Al_2O_3-CaS composite inclusions have little effect on impact properties.

2.2 Effect of S content on impact properties

The relationship between S content and impact properties in Table 1 is shown in Fig. 3(a). It shows that the impact energy significantly decreases with the increase of S content. In order to reasonably control S content and improve the impact properties of steel, the relationship between S content and impact properties of 130