**Characterization of inclusions causing lamellar tearing in S355N**

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**ABSTRACT**

The lamellar tearing is current in welded hot rolled structure steels. It occurs if welding had been parallel to rolling direction. It had shown that the basic causes for occurring lamellar tearing is the existence of elongated non metallic inclusions in steel.

The procedure and acceptance standards for evaluating rolled steel plates to assuring freedom from lamination are assessed in SA-435/SA435M standard. In spite of observation of lamellar tearing by ultrasonic examination the cause and details about occurring lamellar tearing had not been significantly assessed. In this study two resistant and susceptible steel plates had been chosen using ultrasonic examination. Then the microstructural properties of these steel had been compared with another. Furthermore the types, aspect ratio, surface fraction and size of nonmetallic inclusion had been significantly assessed and evaluated by ultrasonic results.

**Keywords:** Lamellar Tearing, Ultrasonic Examination, Nonmetallic inclusions.

**INSTRUCTION**

Diverse defects and problems occurred by improving the usage of steel and various welding procedures in construction making which the lamellar tearing defect is so complicated and dangerous [1].

Lamellar tearing is current in giant welded structures which occur every year in bridges, marine structures, and so on [1-4].

Commercial publications always report the considerable unexpected expenses due to occurrence of lamellar tearing in structures which cause long delay of projects and anxiety of engineers [5].

Many researchers had been tried to investigate about the reasons and mechanism of lamellar tearing occurrence. Primitive studies had been started by Farrar [6] on evaluating the effects of welding design on susceptibility to lamellar tearing in 1969.

Finally the investigators unanimous on factors affecting lamellar tearing based on weakness of z-direction mechanical properties of plates due to existence of nonmetallic inclusions [7-11].

After some years the observation of more defects had been possible by ultrasonic examinations. Nowadays the observation method of lamellar tearing by ultrasonic examinations is described in various standards like ASTM A435. However there is not
information about the characteristics of inclusions which causes the weakness of plate’s 
z-direction mechanical properties as well as susceptibility to lamellar tearing [12, 13]. 
So it seems that evaluating the characteristics of inclusions which cause susceptibility to 
lamellar tearing is more important.

In this study knowing the importance of inclusions on susceptibility to lamellar 
tearing, two types of 40 mm thick S355N steel plate had been evaluated. A resistant and 
a susceptible plate which had been detected in manufacturing of Uremia Causeway 
Bridge by ultrasonic examinations were chosen.

The microstructure of plates, type, size and aspect ratio of inclusions as well as the 
mechanism of susceptible plate’s ultrasonic picks had been evaluated.

Experimental Method

Among S355N steel plates which were used in Uremia Causeway Bridge construction, a 
40 mm thick plate was recognized susceptible to lamellar tearing during ultrasonic 
examinations. So this and one safe 40 mm thick plate had been chosen for detailed 
microstructure studies. These plates analyze is shown in Table 1.

The ultrasonic examination had been done with SONA TEST model normal 4 MHz probe 
perpendicular to the z-direction of plates. The specimens for light optical microscopy were 
mechanically polished to a 1 µm finish and etched using a 2 % nital solution. The 
microstructural properties were evaluated by MPG3 light optical microscopy and MV 2300 
Cam Scan SEM. The size, aspect ratio and surface fraction of inclusions had been determined 
using image analyzer clemex.

To detailed studies about the morphology and volume fraction of inclusions the complete 
inclusions of plates had been extracted.

For achieving this idea, the surface of samples had been polished and cleaned. The primitive 
weight of these samples had been measured by a balance with accuracy of 0.001 g. The samples 
had been solved in 40-60 HNO3 solution. The remained inclusions had been weighted again, to 
calculate the volume fraction of inclusions.

Results and discussion

The pulses of resistant and susceptible plates are shown in Fig.1. The back wall pulses of 
resistant plate have similar distances and their intensity reduces slightly. However the pulses of 
susceptible plate are closer than the resistant one as well as non uniform. The intensity of this 
plate’s pulses reduces sharply which is the basic specification of laminated plates [14].

![Fig. 1 Ultrasonic results of type S355N resistant and susceptible steel plates to lamellar tearing](image)

<table>
<thead>
<tr>
<th>element</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Ti</th>
<th>Nb</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistant</td>
<td>0.16</td>
<td>0.299</td>
<td>1.355</td>
<td>0.023</td>
<td>0.0094</td>
<td>0.002</td>
<td>0.002</td>
<td>0.003</td>
</tr>
<tr>
<td>Susceptible</td>
<td>0.17</td>
<td>0.219</td>
<td>1.395</td>
<td>0.016</td>
<td>0.0097</td>
<td>0.002</td>
<td>0.002</td>
<td>0.003</td>
</tr>
</tbody>
</table>
Fig. 2 shows the microscopic specifications of inclusions in susceptible and resistant plates. It is evident that the spherical inclusions randomly distributed in resistant plate. However the pancake inclusions of susceptible plate are distributed none uniformly.

The microstructure of plates is shown in Fig. 3. The microstructure is consisted of ferrite and pearlite which pearlite is elongated in rolling direction. The pancake inclusions of susceptible plate with a high surface fraction are placed in ferrite and pearlite interfaces which can weaken the plate’s mechanical property.

The inclusions which were extracted completely for detailed evaluations are shown in Fig. 4.
It is evident that the aspect ratio, size and quantity are great in susceptible plate. The aspect ratio of inclusions in resistant and susceptible plates is 1.5, 8 with weight fraction of 0.0077, and 0.014 respectively that is shown in Fig. 5.

Analyzes of this type I MnS inclusions is shown in Fig. 6. It can realize that the inclusions of susceptible plate had more plasticity due to unsuitable rolling temperature (Table. 2) and had been elongated during rolling.

As the inclusions had high potential for nucleation and gathering beside another which results in large and gathered distribution of them [14].

The SEM images of tensile and impact sample’s fracture surface is shown in Fig. 7.

![Fig. 5](image1.png) The aspect ratio and weight fraction of type S355N resistant and susceptible steel plates to lamellar tearing.

![Fig. 6](image2.png) Analyze of inclusions in type S355N steel.

<table>
<thead>
<tr>
<th>Inclusion Type</th>
<th>Temperature (°C)</th>
<th>Relative Hardness (h/h_m)</th>
<th>Relative Plasticity (V_h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MnS</td>
<td>340</td>
<td>0.38</td>
<td>1.45</td>
</tr>
<tr>
<td>MnS</td>
<td>520</td>
<td>0.91</td>
<td>1.16</td>
</tr>
<tr>
<td>MnS</td>
<td>650</td>
<td>0.93</td>
<td>1.08</td>
</tr>
<tr>
<td>MnS</td>
<td>700</td>
<td>1.21</td>
<td>0.83</td>
</tr>
</tbody>
</table>
It is shown that the inclusions in fracture surface of susceptible plate are flattened. However in resistant plate’s fracture surface the amount and plasticity of inclusions is too low.

These fracture surfaces are shown in Fig. 8 without magnification.

It is shown that the inclusions resistant against necking and plastic deformation which shows their low resistance against lamellar tearing [1].

In resistant specimens almost areas are plastically deformed. Here the small size and random distribution of inclusions contribute to full plastic deformation. The MnS inclusions separate from base metal on cooling due to their more thermal expansion coefficient than steel [1, 14]. The existence of inclusions as well as empty spaces (cavity) in separated parts prepares suitable conditions to reflect the pulses. Hereafter in addition to back wall reflection, these areas (pancake inclusions and empty parts) will reflect the pulses too. So there will be more reflection pulses on CRT screen (Fig. 1b). Another interesting point is the gathered distribution of inclusions in susceptible specimen. That gathers beside another like a line and increase the chance of pulses reflection. Such behavior never observes in resistant plate to lamellar tearing.

Fig. 7 The fracture surface of type S355N resistant and susceptible steel plates to lamellar tearing.
CONCLUSIONS

1. The pancake-shaped MnS inclusions have main part on S355N steel plate’s susceptibility to lamellar tearing.
2. In a 40 mm thick S355N steel the MnS inclusions with aspect ratio greater than 8 cause susceptibility to lamellar tearing.
3. In S355N steel the pancake MnS inclusions are closed with another.
4. Inclusions due to having a different type and separation from matrix and making cavity cause the reflection of pulses in ultrasonic testing.

REFERENCES


