The quality advantages of continuous casting (concast) have enabled the production of a wide range of billets for various end applications, including IS:7887 Gr. 3 billets for the fastener industry. This paper discusses the influence of the internal quality of these concast billets on the processing of a wide range of products for the fastener industry. Internal soundness, inclusion volume fraction, and cleanliness were found to have a strong influence on the cracking susceptibility of self-tapping screws and nuts. A high incidence of hairline cracks on nut surfaces was found to be due to a combination of a high volume fraction of inclusions (0.54%) and the presence of complex manganese (Mn) (aluminate-silicate)-type inclusions.

**Keywords:** billets, cracks, self-tapping screws, wire rods

### Introduction

Steel Authority of India Limited (SAIL) has placed increasing emphasis on the development of cost-effective, value-added steel products. Development of IS:7887 Gr. 3 billets has been a step in this direction. The IS:7887 Gr. 3 billets are used extensively for the manufacture of fasteners, such as self-tapping screws, machine screws, nuts, and tinman rivets. The manufacturing process involves two stages: (1) the conversion of billets to wire rods, and (2) the conversion of wire rods to the final product. The first stage involves conversion of 100 by 100 mm (4 by 4 in.) billets into 6 to 8 mm (0.24 to 0.32 in.) wire rods through a combination of hot and cold drawing operations. The second stage involves further processing of the wire rods into the final product. The processing steps involved for the manufacture of self-tapping screws and nuts are shown in Fig. 1.

The major quality requirements of wire rods for fastener applications are moderate strength level (yield strength, 310 to 350 MPa, or 45 to 51 ksi; ultimate tensile strength, 400 to 450 MPa, or 58 to 65 ksi), good cold reducibility, and adequate surface quality. These product attributes are achieved by major steel producers through a combination of low carbon content, adequate refining in the steelmaking stage (to achieve a low sulfur, or S, and low inclusion content), and continuous casting. The benefits of low S and low inclusion contents in improving cold formability, toughness, ductility, and fatigue properties are well known. Oxides and sulfides are examples of non-metallic inclusions in steels and are controlled by limiting the quantity of oxygen (O) and S in solution in the melt.[1-3] In steels that are not aluminum (Al)-killed, silicates are also an important concern. This paper discusses the production of IS:7887 Gr. 3 concast billets and the processing of those billets into self-tapping...
screws, nuts, and tinman rivets. The genesis of crack formation in a few nut and self-tapping screw samples has been examined and correlated with the quality of the input billets.

**Experimental Procedures**

**Alloy Chemistry and Mechanical Properties**

The alloy specification for IS:7887 Gr. 3 is shown in Table 1. The carbon (C) and Mn contents are restricted to a maximum of 0.1 and 0.7 wt%, respectively. The steel can be Al-killed or silicon (Si)-killed, with the Al and Si contents being 0.02 minimum for Al-killed steels and 0.10 minimum for Si-killed steels. Although there are no specified mechanical properties for the billets, the requirements for the semiprocessed wire rods (10 mm, or 0.40 in., in diameter) vary from customer to customer. The following range is typical for many semiprocessed rods: yield strength, 310 to 350 MPa, or 45 to 51 ksi; ultimate tensile strength, 400 to 450 MPa, or 58 to 65 ksi; and elongation, 34% minimum.

**Heat Making**

Two heats of IS:7887 Gr. 3 steel were made in a 130 ton basic oxygen furnace converter and continuously cast into 100 by 100 mm (4 by 4 in.) square billets. The chemical compositions of the two heats, henceforth designated A and B, are shown in Table 1. The steel was Si-killed, with small additions of Al, because deoxidation with Al alone increases the tendency for nozzle choking during casting. The Mn/Si ratio was maintained at ~3 to eliminate the occurrence of breakout. In order to ensure adequate cleanliness and lower the inclusion volume fraction in the steel, the following measures were used:

- S level of 0.03 max was maintained through the use of a synthetic slag and the use of recycled steel that had a low S content (heats A and B).
- Deoxidation through addition of Si, up to 0.25 max (heats A and B)
- Calcium (Ca)-Si treatment to reduce the oxygen level to <30 ppm, followed by argon/nitrogen purging (heat A) for effective desulfurization

Ca-Si treatment was intentionally carried out on only heat A in order to assess the influence of steel cleanliness and inclusion level on the cold reducibility and performance during processing into fastener components.

**Microscopy and Property Evaluation**

Inclusion volume fraction was determined using a quantitative image analyzer, and the analysis of inclusion content was performed using an electron probe microanalyzer.

Tensile samples were prepared in accordance with ASTM 10 (PA 370) specification and tested on a 10 ton universal testing machine at a strain rate of $6.6 \times 10^{-4}$ s$^{-1}$.

**Results and Discussion**

**Macrostructural Analysis**

Typical macrographs of heats A and B are shown in Fig. 2(a and b). Both the heats had a fully dendritic structure with a central hole. The presence of some blow holes at one edge of the billet (heat A) and the formation of fine cracks in the vicinity of the central hole (heat B) were observed. S prints of

![Fig. 2](a) and (b) Typical macrographs of billets belonging to heats A and B showing a fully dendritic structure

<p>| Table 1 Chemical composition of IS:7887 Gr. 3 heats along with specification |
|-----------------------------|-----------------------------|-------------------------------|</p>
<table>
<thead>
<tr>
<th>Sample</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>Chemical analysis, wt.%</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Al</td>
</tr>
<tr>
<td>A</td>
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<td>0.69</td>
<td>0.15</td>
<td>0.008</td>
</tr>
<tr>
<td>B</td>
<td>0.10</td>
<td>0.60</td>
<td>0.23</td>
<td>0.005</td>
</tr>
<tr>
<td>Specification</td>
<td>0.10 max</td>
<td>0.70 max</td>
<td>0.10 min if Si-killed</td>
<td>0.02 min if Al-killed</td>
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