Dangerous steel

Tower crane engineer Felix Weinstein argues that steel impurities are threatening the safety of cranes. Steel produced in ingots from recycled steel is most at risk to contamination. The only solution is extra testing.

A large crack in a steel plate

Cracks in steel laminates supplied to Israel's El-Shar Industries

Crumbling edges is a sign of inclusions - areas where impurities are highly concentrated

When dealing with steel structures we engineers assume that our steel is homogenous, without impurities, and without any other defects. We assume that we are getting the raw material for our structure to meet our needs for strength, elasticity, yield, etc. We use this information to build crane structures that we have calculated to be safe.

Over the past 20 years, computers have developed to help us calculate safe loads for cranes, and enable us to predict the behaviour of our structure with greater certainty. Despite this, we are still seeing failures in our bridges, shafts, beams, and arms from defective steel. There is increasing evidence that cranes, particularly tower cranes, are not being spared from this problem.

"The quality of the material is one of the most important factor in the stability of the crane," said Christoph Schneider, head of project management at tower crane manufacturer Liebherr Biberach, at *Cranes Today* **Crane Safety** 2007.

Steel is an alloy of mostly iron, with between 0.02% and 1.7% of carbon by weight. Carbon and other elements act as hardeners in the iron lattice. The alloying elements in the steel control properties such as hardness, elasticity, ductility (its mouldability), yield strength (the force required to permanently deform it) and tensile strength (the force required to break it). Common grades of steel include S960QL, which has a yield strength of 1,100 N/mm^2, or ST 52, with an ultimate tensile strength of 5,200 kg/mm^2.

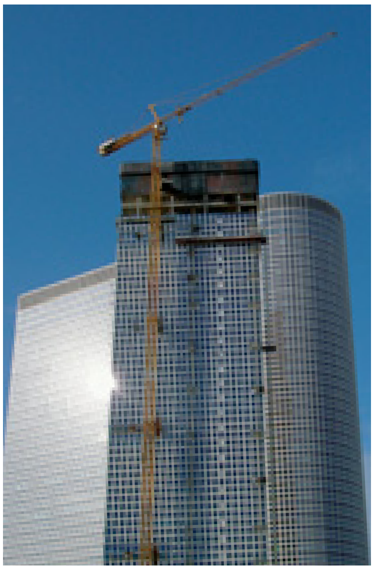
These properties can render a crane unsafe. For example, some tower crane manufacturers use steel that can become brittle and break when hit in cold temperatures, according to Manitowoc Crane Group, the corporate owner of Potain tower cranes. "It is our understanding that some of the local Chinese crane manufacturers use grades Q235B and Q345B steel for their cranes," the company said in a statement. "A crane manufactured with B-grade steel would potentially be at risk of material failure when operating under 20°C (68°F)," it said. In contrast, Potain's plant in China uses Q235C, Q345C and Q345D steels, which are appropriate for operation in cold temperatures. C-grade steels are suitable for operation at 0°C (32°F), and D-grade steels are suitable for work at -20°C (-4°F), it said.

There are two ways to make steel: by converting mined iron ore, or by recycling steel that has already been made.

In an integrated steel mill, a blast furnace burns iron ore mined in its natural form. Then a basic oxygen furnace converts the pig iron into higher-quality steel by adding carbon and removing impurities through chemical reactions inside a vessel. Some of the impurities escape as gas or form a slag, which floats on top of the steel and can be skimmed off. The concentration of the carbon in the molten iron can be seen from the colour of the flame emerging out from the tank cap; today photoelectric sensors perform this job.

In contrast to the large integrated steel mills, there are many more mini-mills, which use electric arc furnaces to melt scrap steel: train rails, pressed cars, iron fence, rebar, or other reclaimed materials. Ingots produced using these sources have many metallic and non-metallic impurities. In theory it is possible to remove all of these impurities by pumping the right gas through the reaction vessel so that it chemically reacts with the impurity to form a slag. But with scrap steels, there are so many impurities that the process is more complicated.

However the steel is made, it needs to be cooled and formed into a usable product. The traditional method is to pour the molten iron into ingots. As the steel cools and hardens, impurities will float to the top. Once the ingot has solidified, manufacturers cut off the



The tower crane jib, and cabin, rely on the strength of steel far below

impurities. It takes considerable technical expertise to know exactly where to cut the ingot. If the cut is too shallow, the steel risks being contaminated. If the cut is too deep, perfectly good steel could be wasted. Also, might commercial pressures force the cut line upward?

In Europe and the USA, this dilemma has largely been superseded by new technology. Most steel is now poured into a so-called continuous casting machine that rolls a single long slab of steel, according to Emmanoel Lima, ThyssenKrupp steel technical marketing specialist. This process is more efficient and produces higher volumes, he said. He also said that continuous casting machines could squeeze impurities to the sides of a slab during the rolling process, for later trimming.

The collection of scrap steel is popular and profitable, and has become an international business. About two thirds (65.4%) of steel in 2005 was produced by integrated steel mills, and a third (31.7%) was produced by electric arc furnaces, which mainly use scrap steel, according to the International Iron and Steel Institute. Today China is the largest supplier, though not the greatest exporter, of crude steel in the world. (The top three exporters in 2004 were Japan, Russia and Ukraine, according to the IISI).

The certificate that is provided with steel provided by the manufacturer or by the supplier only covers the type of the steel received, and perhaps some details about its mechanical properties. But the manufacturing process has the most important role in assuring the steel's quality. In many cases, the steel provided does not measure up to the theoretical strength required of its type.

Poor quality control during the steelmaking process causes two problems in the finished product: cracks and inclusions. A routine test of steel supplied to Israel's El-Shar Industries discovered a crack in 80mm thick ST-52 steel laminates designed for bridge construction.

In the manufacturing process, this sort of molten steel was sucked out of the vessel, leaving slag in the tank. If the suction is not monitored properly, the molten iron may be contaminated. The result is a laminate with a deep crack.

Contamination can also cause inclusions. This defect is characterised by crumbling at the edges of finished product. While building structures the edges of our raw material are the most significant, because in most of the cases, failure starts at the joints of structure, at the edges. In most of the cases this defect renders the product useless unless it can be re-cut for another purpose.

Solutions

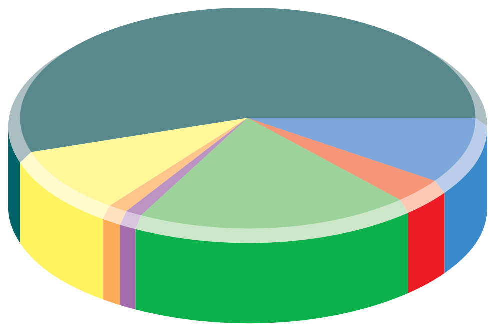
Testing the steel after the manufacturing process and verifying the lack of contaminants requires funding and manpower. Today there are several quality control tests for steel products that manufacturers should carry out.

1. *Metallographic test.* This test can take place only on cold steel, after it had been solidified.
2. *Stimulated brillouin scattering.* Density variations in the steel structure change the path of light passing through it. Engineers use an array of optical fibre sensors to pick up the scatter in a steel bar and compare it with a known reference bar; if they match, the bar is okay.
3. *Laser pulses.* A laser beam fired on a steel bar vaporises a point on the surface for an instant. The effect generates an ultrasonic wave through the steel, which deflects when it hits cracks or inclusions. This wave, in turn, creates a magnetic field that can be detected with sensors. This method, called electromagnetic acoustic transduction, is good for hot steel emerging in a continuous state.
4. *Surface transducers.* In this method, testers send an ultrasonic wave from one transducer to another. This test can only be performed when the steel is cold, because physical contact is required.

Researchers at the University of California, San Diego have developed a method to find internal cracks in railroad tracks using ultrasonic waves. A vehicle drives on the tracks and fires a laser beam pulse at the steel rail. Each pulse generates an ultrasonic wave travelling 1,800 miles/second in the steel rail. Microphones attached to the system detect the telltale reduction in the strength of the ultrasonic signals, pinpointing defects from different kinds of failures.

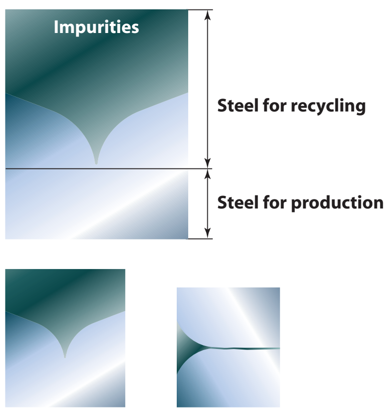
Who produces steel?

China produces 40% of the world's crude steel. In April 2007, total world production was about 110m tonnes.



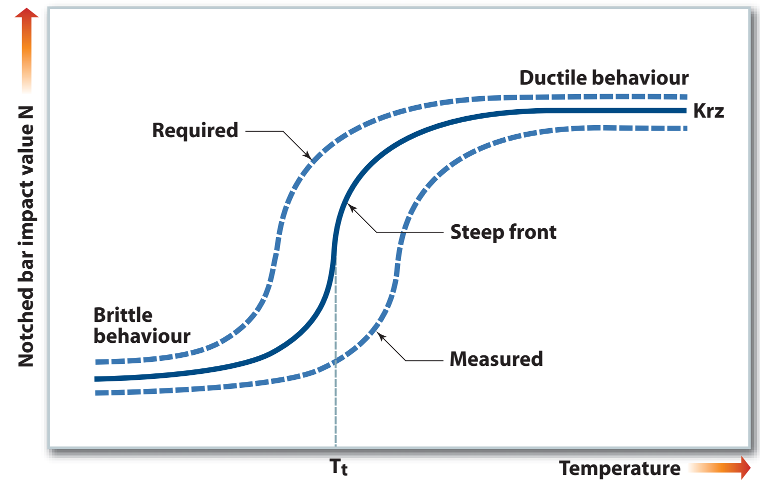
North America	10,483	Africa	1,522
South America	3,986	Russia & CIS	10,464
Europe	21,120	Asia	59,767
Middle East	1,289		

Source: International Iron and Steel Institute



As ingots of steel cool, impurities rise to the top and form a characteristic V-shape. Then the ingot is cut to remove impurities.

The cut must be made beneath the tip of the V. If it is made too high, not only will impurities remain, but the steel will contain a notch that could easily generate a crack.



As its temperature drops, steel becomes more brittle (liable to shatter when struck). This process speeds up at Tt, the so-called steep front, where small changes in temperatures have a big effect on material property. Researchers working for Liebherr have found that copycat tower crane mast sections tend to become brittle at higher temperatures than expected (see also p23).