What Caused Those Cracks?

A forensic analysis was conducted to determine the cause of cracking in a large, steel-making casting machine prior to repairing the cracks

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Gallatin Steel, Ghent, Ky., is a relatively new and innovative steel production facility. Gallatin Steel produces coiled strip steel. The process begins with scrap and ends with coiled steel.

At the heart of this operation is a dual-ladle casting machine called simply the “caster.” This large machine features two balanced arms holding bottom-pour steel ladles — Fig. 1. The cycling of these ladles from right to left and full to empty places enormous cyclic stress upon the supporting structure. In addition, there are severe temperature gradients ranging from ambient shop conditions to that of molten liquid steel — Figs. 2, 3. To meet these challenges and to be productive, Caster Manager Robert Huffman has the support of a skilled crew of steel-making specialists and engineers, who have demonstrated skill in keeping this machine at optimum operation.

During a regular maintenance inspection, a number of small crack-like indications were noted. Upon review, it was decided to weld repair a crack. The caster was fabricated from a foreign equivalent of ASTM A-36 so welding should not have been a problem.

However, the weld repair not only cracked, it cracked the full length of the repair bead. Huffman then called on the welding and forensic engineering services of the H. C. Nutting Co. to do the following:

1. Find out why the repair, which should have been a simple job, failed.
2. Learn why the original weld failed.
3. Determine if there were any other cracks.
4. Discover the depth of the cracks.
5. Determine how to effectively and permanently repair the cracked areas.

Determining the Cause of the Cracks

The authors visited Gallatin Steel in January 2005 to observe the cracks discovered in the casting machine structure. The two were of the opinion that the cracks were due to forces unrelated

Fig. 1 — The dual-ladle casting machine that’s the heart of Gallatin’s steel-making operation.
to the regular production cyclic loading of the machine. They requested an estimate of the total number of cycles on the machine. The general answer was that 70,000 cycles over 10 years was a good estimate, which would put this machine’s welds in the area of initial material fatigue problems.

Observations made during the defect excavations for weld repair supported the early observations that the cracks were probably due to original equipment fabrication welding and were not related to operational stresses on this machine. In general, the cracks were

- In the wrong locations for loading cracks.
- Started from what was believed to be a fatigued heat-affected zone (HAZ) adjacent to the weld.

Two of the cracks were explored to a depth less than \( \frac{1}{4} \) in. and found to continue. They were examined visually, and with dye penetrant, magnetic particle, and ultrasonic inspection technologies. These cracks had a multiple branched appearance indicative of many starts and stops in the growth cycle, i.e., cyclic fatigue.

After observations made during the excavations for repair, it was thought to be highly likely these were stress-induced tearing of the base metal — Figs. 4, 5. The cause was most probably insufficient welding preheat during original fabrication.

It was thought that these cracks started in the heat-affected zone adjacent to the weld, an area that had much lower mechanical properties than the base metal. Notably, both impact and fatigue properties were greatly reduced in this zone. The OEM drawing called for stress relieving heat treatment in some areas, but it was not noted whether the areas with cracks were heat treated to reduce stress.

The base material was analyzed and the AWS D1.1 carbon equivalent values calculated for a limited number of areas tested for chemical content. These values were found to be typical of A-36 structural steel; therefore, it was felt the caster structure could be readily repair welded in place in the shop.

**Repairing the Crack**

One consideration for this repair was the base metal thickness, which required some preheating prior to the removal of the cracks to avoid stress inducement. It was decided to use the air carbon arc cutting technique along with a local preheat of 300°F for crack removal. The preheat was broadly applied such that 300°F was reached 4 to 6 in. away from the crack zone with the crack zone not exceeding 350°F.

**Preventing for the Repair Operation**

Meetings were held at Gallatin Steel with all related people. The proposed welding procedure was discussed and finalized, and the need for a demonstration weld test established. SOFCO Erectors was selected as the repair agency. It performed the demonstration and welder qualification test — Fig. 6. The test sample was analyzed by H. C. Nutting and found to be acceptable. Repair operations were scheduled for late April 2005 during the facility’s next planned outage.

**Repair Operations**

The repair operation began on April 26, 2005 — Fig. 7. The two small diagonal cracks were found to penetrate completely through the 6-in.-thick base plate. These excavations had A36
plate welded into their bottoms with E309L filler metal welded to form a bottom layer in the weld cavity. This was then filled to the surface with E-7018 filler metal using the SMAW process.

The larger, previously weld repaired area was found to have underbead cracking on the prior weld repair as expected and a full section penetration crack like the other two cracks — Figs. 8, 9.

In all three repairs, the amount of final fill required to compensate for cooling shrinkage was underestimated and additional weld metal was required to provide for grinding smoothing operations. All weld repairs were acceptably completed on April 29, 2005.

The following were observed and approved with a welding operations checksheet:
1. Preheat temperature for air carbon arc defect removal.
2. Weld filler metal types.
3. Welding rod oven temperature.
4. In process inspections and final defect removal.
5. Shaping of defect removal cavity for welding.

Follow-up Inspections
A recommendation was made by the authors for Gallatin Steel personnel to observe the repairs at each opportunity and for a Certified Welding Inspector to inspect the welding repairs in one month, then three months, and one year. More than a year later, no recracking has been detected.

Fig. 6 — A cross section from the welding/welder qualification test. This is a narrow, acute angle welding test of 7-in. depth designed to simulate the probable weld groove from the plate cracks in the caster machine.

Fig. 7 — A welder works on the repair to the caster.

Fig. 8 — An underbead crack found in the previously repaired area of the caster.

Fig. 9 — Prior to the repair, the underbead crack was removed.