Non-destructive testing of heavy cast steel (17 August 2009 at 14:37)

Non-destructive testing of heavy cast steel components

Some of the challenges when testing the integrity of very large castings are highlighted here by R Hanus and voestalpine Giesserei Linz GmbH in Austria.

Process for manufacturing heavy cast steel components

For very large parts - after defining the casting technology, building the wooden pattern and construction of the casting begins with the melting and pouring process. Since castings of this size (up to 200 tonnes) must not lead to rejection, the pouring and solidification process is simulated on the computer during the design phase to prevent these from the start. After the solidification time has elapsed (two to six weeks depending on wall thickness and alloy grade) the casting is shaken out.

In this condition the casting must be handled with extreme care since the structure in the cast state is very brittle. Special heat treatments are therefore necessary in order to withstand the high thermal stresses during hot removal of the riser. The temperature range within which the riser is removed is also critical since the stresses, which are determined by different wall thicknesses, must not be overlaid by stresses generated by transformation processes in the microstructure. Together with the chemical composition, heat treatment is the most important step for achieving the required specified mechanical properties such as the basis of creep resistance at high temperatures.

After rough machining, the casting is subjected to non-destructive testing (magnetic particle and ultrasonic). All detected indications not conforming to the acceptance standard must be excavated. After a repeat magnetic particle inspection of the excavations, these are welded, followed by stress-relief heat treatment.

Dimensional checks are performed repeatedly between each production cycle in order to determine whether product dimensions specified for finish machining or use could become critical.

A final non-destructive test is the last production step in the foundry, before the casting is sent for finish machining.

Typical steel casting defects

Shrinkage cavities developed due to the volume deficit between liquid and solid state can be avoided by correct feeding. Hot tears emerge while the casting is cooling down in the temperature range between liquid and solid while it is in a 'doughy' temperature at which the material solidifies completely. Cracks may occur because of obstructed shrinkage at transitions, these are particularly dangerous as they are perpendicular to the surface and start just beneath the flaws, defects in the form of accumulations of non-metallic inclusions, occur predominantly in areas where the casting contacts the underside of moulds and cores.

Although the technological knowhow and therefore defect ratios have improved significantly over recent decades, no heavy casting is the same and robust manufacturing and quality control processes are the basis for high quality castings.

NDT of heavy castings

Non-destructive test methods applied in quality control cycles during the manufacturing process of heavy steel castings include magnetic particle inspection and liquid penetrant testing, ultrasonic examination, radiographic testing, surface hardness testing and dimensional control.

Basically, every casting is tested 100% with magnetic particle methods for surface defects and ultrasonic methods for inner defects. This is done at the first NDT and after a repair cycle (excavating/welding/stress-relieving), whilst the same procedure is repeated for all surface and all welds.

Magnetic particle inspection (MT-testing)

It is worth mentioning the overall magnetisation method for heavy parts as this needs highly sophisticated robust equipment.
multi-directional magnetisation method works with cyclic electric impulses from three heavy current transformers switched after the previous, the time windows of the two following transformers overlapping. Therefore the casting with a rotating tangential vector of the magnetic field in six directions of the three-dimensional system. Compared to the manual method where two probes are always staggered by 90° and cover only two directions of the magnetic field can be achieved using multi-directional magnetisation. The system has a power of 3 x 17,000 Amps effective, full-wave direct current, 36 cables of 150mm² cross-section length of 1,008m.

After testing, the casting needs to be demagnetised, this being performed on the same system using a field with a continuously decreasing field strength, beginning from the maximum applied field strength for testing and ending in 30 steps along an Euler-function and downsizing hysteresis loops.

**Ultrasonic testing (UT)**

Inner defects may be shrinkages, porosity, inclusions and hot tears, each defect type requires the appropriate equipment and procedure. Although both normal and angle probes are applied, testing of complex geometries is a challenge experience and skill of UT-testing of the highest level to be able to find defects in the different locations.

Two important methods to find near-surface defects, which are the most critical, are now described.

**UT testing with twin-crystal shear wave probes.**

Transducers are TMAPF-S 60° 4MHz twin crystal shear wave probe, TMAPF S 45° 4MHz twin crystal shear wave probes, the testing system for twin crystal shear wave probes are checked by watching the dynamic echo from the defect, which is oriented perpendicular to the as-cast surface. For this method the echo height should be about a sound path distance of 20mm.

When all surfaces of the casting are machined, the sensitivity can be adjusted at a 1.5mm side drill hole. In this case the echo height is adjusted to 80% screen height, to give a gain surcharge of 8dB. UT testing should be performed at four directions (4 x 90°) on each machined surface. Best detectability of near-surface testing-field from 2mm to 30mm in depth extensions. Typical casting indications like hot tears in fillets and small surface defects can be detected easily.

**UT testing with twin crystal compression wave probe.**

Transducers are CD-S15-2.5MHz twin crystal compression wave probe. Best detectability of near-surface indications is from 2mm to 50mm in depth extensions. The test methods MT and UT should not be seen as strictly separated procedures, this means the UT testing of heavy steel castings is extremely costly.

**Radiographic inspection (RT-testing)**

Radiographic testing is usually applied only to special zones (weld edges, special fabrication welds etc). In some circumstances RT may be performed as a special request on full volume or critical sections. This needs to be contracts as RT-testing of heavy steel castings is extremely costly.

**UT versus RT**

UT and RT are different testing methods and therefore specifications (recording limits, acceptance standards, also different. However, a correlation on the basis of defect types and detectability has been worked out for examples of evaluation being done on the basis of the authors' theoretical knowledge and experience of hundreds of testing. It contains data for typical types of possible defects on large steel castings, being differentiated in wall thickness, 130mm, 130-300mm, >300mm), and zones where defects appear (rim zone, core zone). As different kinds of zones are differently critical, a 'critical-factor' (1= uncritical, 5= very critical) was introduced.

Detectability by UT and RT is also different although the detectability factor has a similar range (1= not detectable). The resulting chart (fig. 5) shows that those defects which are very critical can be detected much better. This is based on the many possibilities in testing techniques and the knowledge of where we can expect typical types of defects in those areas of the chart where the red line (UT) is below the blue line (RT), i.e. low critical area, casting with special UT-procedures, this means the UT-method is very flexible. Flexibility of the RT-method is very low and not able to improve detectability on the high critical end.

Typical types of indications for steel castings can be detected specifically better with the appropriate beam angle. Crack-like indications and thin shaped indications, parallel and perpendicular to surface, which are typical for the wall thickness, can be detected much better with UT. Near-surface defects, most critical from a load point of view, such as shrinkage-like indications can be reported a little sharper than with UT. But this makes no difference for decisions about acceptance or repair of the indication. An absolute prerequisite is that the testing personnel are specifically educated and experienced on the UT of steel castings and also informed about the critical problems of casting technology.

**Finally**

This article has highlighted the complexity of NDT on large steel castings. It is important to remember that testing methods should not compete but complement each other.
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To view supporting images and figures refer to the full printed version of FJT July/August 2009.

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