Increased usage of duplex materials in manufacturing of pulping equipment

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1 Introduction

In many industrial areas, chemical processes are developing in a direction which is setting ever-increasing demands also on the construction materials of the equipment. This same development has taken place in the pulp and paper industry. The development of pulp and paper processes has been closely linked to the development of stainless steels and both industrial sectors have strong connections in the Nordic countries. Due to demands from the early pioneers in the pulp and paper industry in the Nordic countries and the constant search for better acid-resistant materials, the stainless steel industry in the Nordic countries was born and has become a world leader in this field.

Experience in this field goes back many years and suppliers have been involved in replacing pulp digesters made of a riveted carbon steel construction and in the case of the sulfite industry, vessels lined with acid proof bricks. The next step was a process where old digesters were lined internally with approximately 3mm stainless steel sheets held by a vacuum system between the parent metal and the liner. In some cases the digesters were strip-lined with 150mm wide stainless steel strips. This was a mammoth task which, however, served its purpose since there was really no other way, and solid stainless steel vessels were out of the question in those days due to the high prices of heavy wall thicknesses. Later on solid stainless steel vessels have replaced digesters manufactured from clad steel material. The introduction of the Avesta cold-stretching method made it possible to manufacture solid stainless steel vessels with 40–50% lower wall thickness thereby being price competitive with standard solid stainless steel vessels. How-

<table>
<thead>
<tr>
<th>Material</th>
<th>Price factor</th>
</tr>
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<tbody>
<tr>
<td>304L</td>
<td>1</td>
</tr>
<tr>
<td>316L</td>
<td>1.3</td>
</tr>
<tr>
<td>2304</td>
<td>1.5</td>
</tr>
<tr>
<td>2205</td>
<td>1.6</td>
</tr>
<tr>
<td>317L</td>
<td>2.3</td>
</tr>
<tr>
<td>2507</td>
<td>3.0</td>
</tr>
<tr>
<td>904L</td>
<td>3.4</td>
</tr>
<tr>
<td>254 SMO</td>
<td>4.7</td>
</tr>
<tr>
<td>654 SMO</td>
<td>7.5</td>
</tr>
</tbody>
</table>

Table 1. Relative fabrication material prices.

Figure 1. A flow sheet of a typical pulping process.
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Figure 2. Usage of duplex material in a modern pulping line.
1 Solid duplex material
2 Vats and conveyor screws, or even totally of duplex
3 Upper shell parts

Figure 3. Wall thickness of a digester when fabricated of different materials, design temp. 204°C, pressure 13.5 bar.

1) 8mm corrosion allowance

ASME

A516:70
304
304-clad
2205-clad
SAF 2304
2205

TKN

31
25
24
23
21
19

30
28
22
20
17
15

1) 8mm corrosion allowance
ever, cold stretching was not approved globally by the pressure vessel authorities and even this technology is now part of fabrication history since 2205 duplex material was introduced. Today almost all pressure vessels used in the pulp and paper industry are manufactured of duplex materials, mainly digesters used for the cooking of chips in alkali conditions, as well as reactors in the oxygen delignification and bleaching processes, which work both in alkali and acid process conditions. Furthermore, duplex material is increasingly used also in the fabrication of non-pressurized vessels, as well as main process equipment.

1.1 Why duplex?
The obvious main reason for the increased use of duplex materials in the pulp and paper industry is economics. Material savings due to the favorable strength properties of duplex materials give clear benefits. On the other hand, special expertise is required in fabrication, which is discussed later in this presentation in more detail.

1.2 Cost comparison
While some alloys have higher pitting resistance than others, it is clear that the more highly alloyed steels are significantly more expensive than the lower alloyed steels. Table 1 shows the relative prices of different materials used for fabrication of pulping equipment.
It is interesting to note that the duplex steels offer very good value in terms of pitting resistance against price. As an example: though the PREs are equivalent, the price of SAF 2205 is about half that of 904L. This should, however, be used with caution, as we have found that impurities, acid concentrations, etc., can have an important effect on corrosion resistance.

2 Typical applications
A typical pulping process consists of various process steps. In the first step, wood chips are cooked at a high temperature and pressure to release the lignin which glues the wood fibers together. This is followed by pulp washing, where the cooking liquor is removed, after which impurities are screened out of the pulp. The two final main process steps consist of bleaching the pulp in high brightness, then pulp drying and baling. Figure 1.
The use of duplex material first began in the fabrication of pressurized pulp digesters a few years ago. Figure 2 shows roughly the extent to which duplex material is used today in the pulping process.

2.1 Pulp digesting
In sulfite pulping, where the chips are cooked in acidic conditions (pH 2–4) digesters have been manufactured from 316L though the tendency is to higher alloys. Corrosion resistance has been studied in real conditions. Table 2 shows the superior resistance to pitting of SAF 2205, based on coupon testing in a sulfite digester for eight months (ref. 1).

<table>
<thead>
<tr>
<th>Steel grade</th>
<th>Corrosion rate (mm/year)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>316</td>
<td>0.011</td>
<td>Slight etching under deposits, shallow pits under crevice washers, max. 0.10mm</td>
</tr>
<tr>
<td>317L</td>
<td>0.009</td>
<td>Slight etching under deposits, shallow pits under crevice washers, max. 0.10mm</td>
</tr>
<tr>
<td>2205</td>
<td>0.005</td>
<td>Slight etching under deposits, max. 0.04mm</td>
</tr>
</tbody>
</table>

*Table 2.*
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In kraft pulping substantial savings can be achieved when using duplex 2205 material, taking into consideration the different codes (in this case the ASME Code and the Swedish Pressure Vessel Code (TKN)). As can be seen, a saving of 50% in material thickness is achieved compared to using solid carbon steel and a slightly lower saving as regards the austenitic grades. Figure 3 shows the material savings in batch digester fabrication for kraft pulping. According to the Avesta survey, September '98, altogether 114 digesters, including both continuous and batch digesters, have been fabricated of duplex material (table 3). As a conclusion, the following differences in digester wall thickness can be achieved:

- Duplex digester wall
  - 76% of solid 304 wall (ASME)
  - 54% of solid 304 wall (TKN)
  - 79% of clad steel wall (ASME)
  - 68% of clad steel wall (TKN)

The biggest batch digesters made from duplex 2205 are 400m³ which today is our standard size for new digesters. Figure 4 shows a 400m³ batch digester under fabrication (Metso Pori Works, Finland). Pressurized vessels in general, manufactured by our company, vary from 400 to 1100m³ and the wall thickness varies between 4 and 30mm.

2.2 Washing and screening
Single pieces of process equipment, such as pulp washers and presses, have traditionally been manufactured of various stainless steel grades, but today duplex materials are increasingly used even for fabrication of parts of those. In kraft pulping, water quality and the degree of process closure are the major influences on the environment in brown stock washing. Corrosion rates of more than 5mm on carbon steel have been reported. Depending on pH control, duplex steels are proving to be the most suitable. Duplex materials are typically used today also in the fabrication of filter drums and pulp conveyor screws. In big modern pulping lines wash presses are, however, increasingly being used instead of traditional drum filters. The TwinRoll press (figure 5) is a typical washing apparatus. Earlier press vats were typically made of duplex material, today even all parts of certain press types are fabricated of duplex. Just recently we have also started to fabricate traditional drum washers from duplex. Figure 6 shows a duplex vacuum washer drum in the workshop.

2.3 Oxygen delignification
The majority of O₂ stages operate at medium consistency and 316L has generally been used as the fabrication material. SAF 2205 is constantly gaining ground at the expense of other grades. Today almost all O₂ reactors made by our company are of duplex 2205 as well as all the batch digesters. According to the Avesta survey of 1998, various pulping equipment suppliers in the world have so far fabricated totally 107 oxygen reactors of duplex material. Figure 7.

2.4 Bleaching
Besides a similar type of reactors and washers as in the preceding process
stages, typical for a pulp bleaching process are large pulp storage towers. Such storage tanks and towers have previously been constructed from such materials as solid concrete with tile lining, carbon steel with 2mm thick stainless steel cladding, or solid stainless steel austenitic material. In the case of vessels manufactured from solid austenitic materials, the costs are high due to the relatively low yield strength giving around 40% higher wall thickness than when using duplex 2205 material. However, in the case of very large storage towers, the wall thickness of the bottom part is so high that it is still economical to make that part of carbon steel with SS lining (figure 8).

One example of a storage tower is 16 meters in diameter and has a height of 33 meters, specified in 316L. The superior strength of SAF 2205 made it possible to design the tanks in lighter gauge material making their cost lower than their 316L counterparts. For this reason the specification was changed to SAF 2205. Due to the practicality of the construction the lowest thickness used has been 6mm. Also in the case of bleach plants, duplex 2205 materials are used for some of the bleach filters, depending on their position in the bleach sequence. In this case too, the high strength and corrosion resistance is the deciding factor.

Our prediction is that duplex materials will eventually replace most austenitic materials in the pulp and paper industry with a few exceptions in the bleaching process.

3 Fabrication of pressure vessels of duplex steel for pulp mills

Pori Works fabricated the first duplex 2205 pressure vessels in 1992. Introducing a new material into the workshop went relatively well because of the long experience in fabricating pressure vessels and machines of different austenitic stainless steels. So far 118 pressure vessels for pulp mills have been fabricated of solid 2205 duplex steel at our workshop: 61 vessels for South-East Asia, 48 vessels for Europe and 9 vessels for North America (figure 9).
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The pressure vessel codes used so far for fabrication have been:

- SFS (Finnish requirements), based on German code
- ASME Code
- TKN (Swedish code)
- ADM (AD Merkblatt, German code)

Plate materials used – depending on requirements – have been:

- W. 1.4462 AD W2 + VdTÜV Wb 418
- ASME SA 240 S31803
- Avesta Sheffield 2205 PKVP-03.155 Rev. 2

Edge preparation for shell plates is made by machining. Double-V or double-U grooves are used depending on the material thickness. Careful edge preparation helps keep repair costs low.

Semi-spherical and elliptical heads delivered in segments are ordered as cold formed without annealing. The sub-supplier makes edge preparation and pre-fit-up. Material thickness of vessel shells has been 4 to 40mm. This makes submerged arc welding (SAW) an attractive process for most longitudinal and circumferential weld seams of shell and major nozzles. Other pressure-retaining parts are welded using the shielded metal arc process (SMAW), see figure 4. For some non-pressure-retaining parts flux-cored arc welding (FCAW) is used.

Welding instructions (WPS) shall be based on welding procedure tests. For 2205 material the control of heat input during welding is necessary to avoid reduction of corrosion resistance and toughness of the welded joint. The allowable range depends on the case but normally it is 1.0 to 2.5kJ/mm. It is relatively easy to keep within that range while most of the welding is flat position. Documented spot checking helps the welders to keep in mind that it is important to follow the welding parameters given in WPS.

The number of necessary welding production tests depends on the requirements of each code. So far we have not met any problems in fulfilling the test requirements. The qualifications of welders and plate workers for 2205 work shall always contain a theoretical part even if they are already familiar with austenitic stainless steel work. One can pass the welding test but still make expensive mistakes in actual work. Qualification tests should be done using 2205 base and filler material even if the qualification standard allows using austenitic material.

The quality control of a 2205 pressure vessel is based on a quality plan made soon after the order. The NDE methods based on the code used are visual (VT), dye penetrant (PT) and radiographic examination (RT). All the welds are examined visually 100%. PT can be 100% for all nozzle to shell welds (ASME) or 25% of shell weld seams and 10% of nozzle and fillet welds (ADM). Typical examination RT is 100% for longitudinal welds and 25% (ADM) or spot (ASME) for circumferential welds. The percentage of rejected X-ray films is used for measuring welding quality. This figure has been less than 2% during the past few years, which has been considered acceptable.

<table>
<thead>
<tr>
<th>Welder</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ahlström</td>
<td>1</td>
</tr>
<tr>
<td>Beloit</td>
<td>15</td>
</tr>
<tr>
<td>Kværnær</td>
<td>5</td>
</tr>
<tr>
<td>Sunds</td>
<td>83</td>
</tr>
<tr>
<td>Other</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td>114</td>
</tr>
</tbody>
</table>

Table 3. Duplex digesters fabricated until 1998.
4 Conclusions

SAF 2205 with its high strength and corrosion/erosion properties is becoming more popular. It can often be justified on a cost basis. Wall thickness reductions of 50% on carbon steel and 35% on clad steel can be achieved. A kraft pulping process includes a large number of pressurized reactors and atmospheric large tanks and towers, as well as various main equipment. Total savings achieved through favorable characteristics of duplex materials are huge, considering that a total cost of an average fiber line equipment delivery can be up to MUSD 100.

References

1 Committee of steel producers of AISI; stainless steel for pulp and paper manufacture.
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