Forta FDX 27 – duplex stainless steel for high strength gasket plate heat exchangers

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Abstract.

Outokumpu has developed a new duplex stainless steel with improved formability compared to other duplex grades. The so-called Forta FDX grades allows the utilization of duplex grades in more forming intensive products previously not possible and at the same time benefit from other duplex stainless steel properties for increased application performance.

In this paper a Gasket Plate Heat Exchanger (GPHE) plate is formed with the new duplex grade Forta FDX 27 and compared to the baseline grade Supra 316L/4404. Detailed material characterization, strain measurements and Finite Element Analysis (FEA) were performed to further investigate the case. Small differences in measured strain distribution between Forta FDX 27 and Supra 316L/4404 were found after the stamping operation for both material grades and for the same design feature. Strain measurements showed reasonable agreement between measured experimental results and the numerical simulation for Forta FDX 27. Additionally, FEA predicts an improvement of the final strength of the product up to 30 % at the final configuration by using Forta FDX 27 instead of Supra 316L/4404.
1. Introduction
Plate heat exchangers (PHE) are often the preferred choice in heat exchanger applications due to a compact and flexible design. However, in high pressure applications PHE’s have leakage limitations, especially the gasket sealed ones. High pressure heat exchanger applications are dominated by tubular designs but several new PHE designs have been introduced which are claimed to overcome many of these limitations. These are preferably welded or brazed to avoid leakage in the gasket area [1].

No matter which PHE design is used (welded, brazed or gasket), they would all benefit from using a more high strength material to reduce the risk of plate collapse in the high range of the pressures and subsequent leakage problems. High strength material is often correlated to limited formability properties. Therefore, the plate design should to be adjusted with regards to the restrictions in formability [2]. The adjusted design must in many cases accept a lower surface area and thereby a lower heat transfer efficiency, leading to reduced performance. This paper describes a way to overcome this problem by introducing the formable duplex grade Forta FDX 27.

2. Duplex stainless steel
Typical materials used for Gasket Plate Heat Exchangers (GPHE) are standard austenitic stainless steel grades such as Core 304L/4307 and Supra 316L/4404. Alternative high strength stainless steels are the so called duplex stainless steel grades, consisting of a balanced combination of the ferritic and austenitic microstructure. Apart from the higher strength, also higher fatigue strength, erosion resistance and an increased resistance to stress corrosion cracking is offered by the duplex grades. Although the standard duplex grades, such as Forta DX 2205, have a relatively good formability, it is not sufficient for the complex pattern designs necessary for many high performance GPHE products.

The newly developed formable duplex stainless steel grades - the Forta FDX concept - improve the formability limitations of standard duplex stainless steel and offer a way to produce high strength GPHE plates with the same or close to the same surface area as traditional austenitic stainless steel. The Forta FDX grades allows the use of duplex in parts where it has not been possible before due to forming limitations and also that it is often possible to use existing stamping tools as for the corresponding standard austenitic grades. Other studies of similar topic can be found in [3, 4].

The chemical composition of some selected grades is shown in Table 1, comparing the Forta FDX grades with the standard duplex grade Forta DX 2205 and the two standard austenitic grades Core 304L/4307 and Supra 316L/4404.

| Outokumpu steel names | EN    | UNS     | C    | Cr    | Ni    | Mo  | N    |
|-----------------------|-------|---------|------|-------|-------|-----|------|
| Forta FDX 25          | 1.4635| S82012  | ≤ 0.05| 19.0-20.5| 0.8-1.5| 0.1-0.6| 0.16-0.26|
| Forta FDX 27          | 1.4637| S82031  | ≤ 0.04| 19.0-22.0| 2.0-4.0| 0.6-1.4| 0.14-0.24|
| Forta DX 2205         | 1.4462| S32205  | 0.02 | 22     | 5.7   | 3.1 | 0.17 |
| Core 304L/4307        | 1.4307| S30403  | 0.02 | 18.1   | 8.1   | -   | -    |
| Supra 316L/4404       | 1.4404| S31603  | 0.02 | 17.2   | 10.1  | 2.1 | -    |

Table 1. Typical chemical compositions of selected duplex stainless steels and standard austenitic grades for reference.

Duplex stainless steel is suitable for all forming processes available for stainless steel. The high proof strength (Rp0.2) compared to austenitic stainless steel grades; see Table 2, can impose some differences in forming behavior depending on chosen forming technique, such as an increased tendency to springback. This point is particularly relevant to forming of any high strength steel.

The Forta FDX grades have excellent formability properties thanks to the Transformation Induced Plasticity (TRIP)-effect, where some amount of the austenitic microstructure is transformed into...
martensite during plastic deformation. The TRIP-effect offers a balanced work hardening rate resulting in an enhanced uniform elongation ($A_u$) and higher work hardening ratio at large (plastic) deformations in comparison to other duplex grades. These mechanical properties make the Forta FDX grades more suitable for manufacturing of components with stretch forming as the primary forming operation, which is the case for GPHE forming. The unique formability properties of the Forta FDX grades compared to other stainless steel grades are illustrated in Figure 1. In this paper, a direct conversion to Forta FDX 27 is made to replace the traditional grade Supra 316L/4404 in order to improve the high pressure capacity of an already existing GPHE design. The reason for comparing Forta FDX 27 to Supra 316L/4404 is the need for similar corrosion resistance, which is provided by Forta FDX 27 with the additional improved strength. The corrosion resistance is also not affected by the TRIP-effect [5].

Table 2. Typical mechanical properties of selected duplex stainless steels and standard austenitic grades for reference. The nominal thickness is 1.0 mm and the numerical data are valid for transversal direction [6].

| Outokumpu steel names | EN     | UNS   | $R_{p0.2}$ [MPa] | $R_m$ [MPa] | $A_{80}$ [%] | $A_g$ [%] |
|-----------------------|--------|-------|------------------|-------------|--------------|----------|
| Forta FDX 25          | 1.4635 | S82012| 650              | 850         | 38           | 34       |
| Forta FDX 27          | 1.4637 | S82031| 650              | 850         | 38           | 34       |
| Forta DX 2205         | 1.4462 | S32205| 690              | 890         | 25           | 17       |
| Core 304L/4307        | 1.4307 | S30403| 280              | 630         | 58           | 52       |
| Supra 316L/4404       | 1.4404 | S31603| 285              | 610         | 56           | 47       |

Figure 1. The elongation versus the proof strength for different types of stainless steels, illustrating that the Forta FDX grades form a group with a unique combination of properties.

3. Mechanical properties of investigated materials
The materials used in the comparison were Forta FDX 27 and Supra 316L/4404 with a thickness of 0.6 mm. An overview of selected material properties is presented in Table 3. Mechanical properties were obtained by standard tensile testing in three directions (0°, 45° and 90° to the rolling direction). True stress strain curves for the materials are compared in Figure 2. The higher strength of Forta FDX 27 is clearly noted while still having good formability.
Table 3. Selected mechanical properties (transversal direction) for the investigated materials, 0.6 mm thickness.

| Material     | $R_{p0.2}$ [MPa] | $R_m$ [MPa] | $A_g$ [%] |
|--------------|------------------|-------------|-----------|
| Supra 316L/4404 | 270              | 588         | 47        |
| Forta FDX 27    | 648              | 852         | 37        |

Figure 2. Comparison of true stress-strain curves for the materials in this study. Transversal (T) direction.

4. Forming Limit Curve (FLC)

The Forming Limit Curves (FLC) for the materials in this study are presented in Figure 3. It is seen that Supra 316L/4404 has a higher FLC than Forta FDX 27, which is to be expected from the uniform elongation ($A_g$) values presented earlier. The FLCs were obtained with the Nakazima test method and evaluated before the onset of necking.

Figure 3. Forming Limit Curves (FLCs) for the materials involved in this study.
5. Forming evaluation of Forta FDX 27 for gasket plate heat exchanger application

GPHE plates of Forta FDX 27 were formed in the same tools as made for Supra 316L/4404. The sheet metal thickness was 0.6 mm. A direct comparison could therefore be made between the two grades. Figure 4 (left) shows the heat exchanger part design after forming in production tools using Forta FDX 27, with the same configuration for the FEA setup shown in Figure 4 (right). The regions of interest are also shown in Figure 4 (left), named Region 1 and Region 2. These were chosen as the most important parts from a forming perspective.

![Figure 4](image1.png)

**Figure 4.** Formed GPHE plate with investigated regions (left), and final configuration from simulation software Impetus Afea Solver (right).

5.1 FEA setup and analysis

The feasibility of Forta FDX 27 for this application was analysed through Finite Element (FE) simulations of the forming operation. The FEA software used was Impetus Afea Solver, utilizing a solid element formulation for the blank material for the sheet metal forming analyses. A material model utilizing mechanical properties from the three tested material directions was used for the blank material. The tooling was modelled as a rigid material. The strain distribution of the two materials and regions are shown in Figure 5. A safety margin of 10% is added to the FLCs, indicated with dashed lines below the measured FLC. The principal strains from FEA show that Forta FDX 27 has higher amount of principal strains for both regions compared to Supra 316L/4404, but still below the FLC. Region 1 is dominated by stretch forming and Region 2 closer to plane strain.

![Figure 5](image2.png)

**Figure 5.** Comparison of strain distribution from FEA for the two materials and regions.
From FEA the strength properties increase of the final formed part can be estimated. The overall strength was approximately 30% higher for Forta FDX 27 compared to Supra 316L/4404. This increase in strength is beneficial for the final GPHE product performance within the high pressure application. An illustration of the strength increase is shown in Figure 6, where the strength has been normalized and compared between Forta FDX 27 and Supra 316L/4404.

![Figure 6](image)

**Figure 6.** Strength distribution (normalized) after forming for 0.6 mm thickness. Supra 316L/4404 (left), Forta FDX 27 (right).

### 5.2 Experimental try-out

As stated earlier, the Forta FDX 27 try-out was conducted in the same tools as the Supra 316L/4404 material. No modifications were done to the tool design when forming Forta FDX 27. The lubrication system used is the same as for normal production. Sheets were successfully formed with both grades thereby proving the concept that Forta FDX 27 offers the same functional surface area as Supra 316L/4404 for this particular GPHE design. A strain analysis was performed with a 3D strain measurement system to investigate any areas of critical strain levels. The grid size was 1 mm². The results from the experimental try-out show that the strains for Forta FDX 27 are somewhat higher in Region 1 compared to Supra 316L/4404, and of similar magnitude in Region 2. The measured strains for Forta FDX 27 are below the FLC safety margin.
Figure 7. Comparison of strain distribution from the experimental try-out for the two materials and regions.

5.3 Comparison of strain measurements between experimental try-outs and FEA for Forta FDX 27
The strains were compared between the experimental try-outs and FEA for Forta FDX 27, see Figure 8. It can be seen that FEA shows reasonable agreement with experimental strain measurements, showing the usability of Computer Aided Engineering (CAE) tools for development work for new design ideas. Some measurement points for the experimental strains are somewhat higher for Region 1.

Figure 8. Comparison of strain distributions for Forta FDX 27 between FEA and experimental try-out for the two regions.
6. Conclusions
Forta FDX 27 was used to produce GPHEs and comparisons were made with the same GPHE design produced with Supra 316L/4404 of the same thickness. The following conclusions can be drawn:

- Forta FDX 27 was formed with the same tool design as for Supra 316L/4404.
- No cracking occurred in Forta FDX 27 during forming of the GPHE plates.
- Small differences in measured strain distribution between Forta FDX 27 and Supra 316L/4404 were found. Due to the lower FLC level of Forta FDX 27, the safety margin for fracture is somewhat lower compared to that of Supra 316L/4404.
- Strain measurements showed reasonable agreement between experiments and FEA for both regions for Forta FDX 27.
- FEA gives an estimated strength increase of 30% in the formed part if using Forta FDX 27 instead of Supra 316L/4404.

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References
[1] Chater J 2016, Heat Exchangers: a large and growing market, Stainless Steel World 28 pp 30-35
[2] Moshfegh R, Guan Li, Hailan He, Sun CC, Xiumei Ma 2015, Using duplex grades in demanding forming operations – A CAE based product development, Outokumpu ACOM 1
[3] Moshfegh R, Madsen E, Storgaard Friis K, Groth A 2014, FDX™ grades the new duplex stainless steels with enhanced formability properties – a customer case study, Proc. Pump Summit 2014, Düsseldorf
[4] Schedin E, Moshfegh R, Madsen E, Storgaard Friis K, Groth A 2015, Forta FDX grades the New Formable Duplex Stainless Steels – a customer case study, Proc. of 5th China Int. Duplex Stainless Steel Congress, Beijing
[5] Schönning M, Wegrelius L, Johansson E 2016, Pitting and H2S Corrosion Resistance of the New Formable Duplex Grades, NACE International Corrosion Conf.
[6] Outokumpu Sheet Metal Forming Handbook 2017, 1st ed.