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A NOVEL TYPE OF ALL-STAINLESS STEEL PLATE HEAT EXCHANGER

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ABSTRACT

A novel type of very compact all-stainless steel gasket-free plate heat exchangers, the AlfaNova[§], has recently been introduced on the market. The heat exchangers are made of stainless steel plates bonded together using Transient Liquid-Phase (TLP) bonding technology. A breakthrough iron-based filler having a composition very similar to that of stainless steel type EN 1.4401 (UNS S31600) is used for the bonding. This gives the heat exchanger homogeneous properties, resulting in features such as a chemical resistance similar to that of the stainless steel plate and an excellent resistance to fatigue originating from pressure variations. Extensive testing has shown that heat exchangers manufactured with this technology are superior to the prevailing copper and nickel brazed PHE:s in terms of e g temperature performance, corrosion resistance and pressure fatigue resistance. In many applications requiring stainless steel the AlfaNova has proven to be the most cost effective heat exchanger choice for the user.

INTRODUCTION

The last decade has seen a number of new types of gasket-free compact heat exchangers introduced on the industrial marketplace. Why gasket free? There are three main reasons that drive the evolution of gasket-free compact heat exchangers. The first and perhaps foremost is the chemical compatibility of the elastomer and the fluid inside the exchanger. A second reason for using gasket-free is the limitation in operating temperature. Most standard elastomers do not allow continuous operation above 160-170 °C. Special high-temperature elastomers for use up to about 190-200 °C have been developed, but in general these qualities range from costly to very costly. A third reason for wanting to avoid gaskets in many industrial applications is the potential risk of a gasket failure. Vendors and users of plate heat exchangers have learned this over the years and in some ways the gasketed plate heat exchanger (PHE) has been assigned to the “easy and harmless” region on the map of industrial heat exchanger applications.

Up till now there has basically been two remedies to the gasket-related problem areas; welding and copper or nickel brazing. For the all-welded heat exchanger the compatibility problem applies only to the metallic material of construction. Higher temperatures are generally not a problem and the risk of leakages is transferred from elastomers to a seam weld and, thus, generally reduced. The traditional brazed PHE (BPHE) has, for various reasons, not been widely accepted in industrial applications. One reason is the presence of copper, which is subject to corrosion in many industrial applications. Copper is also regarded as a potential health hazard in many food-

[§] AlfaNova is a trademark owned by Alfa Laval Corporate AB type industries. Replacing copper with a nickel-based filler was seen as a way to increase the versatility of the brazed units, but nickel-brazing met with many difficulties and the result was units with often decreased mechanical performance as a trade-off.

Several years of intense R&D efforts at Alfa Laval have recently resulted in a breakthrough type of compact heat exchanger, the AlfaNova, which combines features such as gasket-free, all-stainless steel and TLP bonding. As reliability is key in any process industry special attention has been paid to investigate the two main reasons for failure of gasket-free PHE:s; corrosion and fatigue.

This paper briefly describes the TLP bonding technology, but focuses on issues around corrosion and mechanical properties. Several comparisons between copper and nickel brazed and TLP bonded PHE:s are presented.

TLP BONDING TECHNOLOGY

The AlfaFusion[§§] joining technique comprises Transient Liquid-Phase (TLP) bonding using a new type of iron-based filler. The nominal chemical compositions of the new filler and a typical stainless steel quality, EN 1.4401 (UNS S31600) are shown in Table 1. Evidently, the chemical composition of the AlfaNova filler was designed to be similar to that of stainless steel. The melting point of the filler has been reduced by alloying with melting point depressants, namely Silicon and Boron.

Table 1 Nominal composition of EN 1.4401 and AlfaNova filler respectively, weight%.

	C	Cr	Ni	Mo	Mn	Si	Fe
Stainless steel 1.4401	0.04	17.2	10.2	2.1	1.5	0.75	Bal
AlfaNova filler		17	12	2.2	1.6	MP*	Bal

* Melting point depressant

The principle for TLP bonding is that the applied filler solidifies isothermally at the bonding temperature due to changes in the composition. Normally, this solidification process is controlled by diffusion of elements from the melted joint into the base material. In the AlfaFusion case, the filler and the base material interact extensively. Consequently the solidification in the AlfaFusion process is not only due to diffusion, but also the result of the mutual interaction between the filler and the base material, resulting in a joint similar to a weld. Comparative cross sections from a Nickel braze respectively an AlfaFusion bonded sample are shown in Figure 1 and Figure 2.

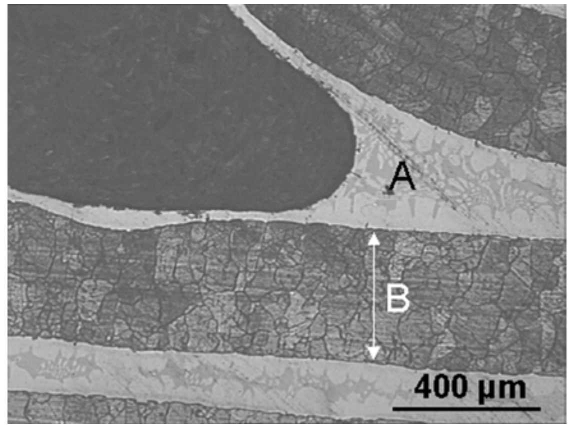

Figure 1 Cross-section of two plates made of type EN 1.4401 bonded with a BNi-5 braze filler (A), after electro etching with 6V in 10% oxalic acid at room temperature. It should be noted that the base material thickness after brazing (B) is similar the thickness before the brazing.

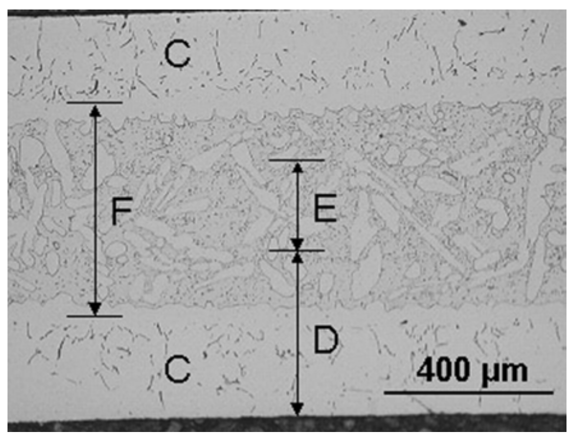

Figure 2 Cross section of two plates (C) made of type EN 1.4401 bonded with the AlfaFusion process. It is significant for the AlfaFusion cross section that the filler thickness, which is marked (E) before heating, has changed significantly to (F) after bonding. This is due to the interaction between the base material and the filler, creating a joint similar to a welded joint. The plate thickness before heat treatment is marked as (D) in the picture.

[§§] AlfaFusion is a trademark owned by Alfa Laval Corporate AB

MECHANICAL PROPERTIES

Experimental Techniques

All mechanical tests were conducted with heat exchangers made up of ten 0.35 mm thick plates in stainless steel type EN 1.4401, one frame plate, one pressure plate and four connections. The total outer dimensions were approximately 210*80*60mm (length *width*height). The copper and nickel-based fillers were applied as foils and the iron based filler as paste. The nominal chemical compositions of the fillers are shown in Table 1 (AlfaNova) and Table 2. In this part of the study only three types of filler were studies; AlfaNova, copper and nickel/MBF-51.

Table 2 Nominal composition of the studied fillers, weight%.

Filler	Cr	Ni	Mo	Cu	Fe	MP depr *
Copper **)				100		
Nicrobraz 30 ***)	19	Bal				Si
Nicrobraz 3002 ***)	15	Bal				Si
Nicrobraz 3003 ***)	17	Bal				Si, B
MBF-51 **)	15	Bal				Si, B
FP-613 ***)	29	Bal				Si, P

*) Melting point depressants.
**) Applied as foil.
***) Applied as paste.

The heat exchangers were subject to three different types of tests:

1. Burst test. The heat exchangers are burst tested by increasing water pressure on one side until leakage.
2. Pressure fatigue test. The heat exchangers are pressurized with oil on one side with an alternating pressure ΔP, which is the difference between the maximal and the minimum pressure. Each cycle takes approximately 2 seconds.
3. Temperature fatigue test A flowing media (water) is passed through one side of the heat exchanger. The water is alternating between the ambient tap water temperature and a hot water (or steam) temperature. The difference between those temperatures is called ΔT. The total cycle length is approximately 90 sec.

Results

The burst test results are presented in Table 3. The results are averages of at least ten heat exchangers per value.

Table 3 Burst test results

Heat exchangers joined with:	Burst pressure (bar)
Copper	180
Nickel/MBF-51	95
AlfaNova	120

The pressure fatigue results are presented in Table 4. The results are an average of at least four heat exchangers/ value. After 1 000 000 cycles, none of the four tested AlfaNova heat exchangers had failed. Therefore the ΔP was increased to 40 bar for the same heat exchangers. The four units failed in the range of an additional 330 000 to 482 000 cycles. The results from the temperature fatigue testing are presented in Table 5.

Table 4 Pressure fatigue test results when tested with a ΔP of 30 bar, 0 to 30 bar.

Heat exchangers joined with:	Log. average of cycles to failure
Copper	72 000
MBF-51	17 000
AlfaNova	>1 000 000

Table 5 Temperature fatigue test results when tested with a ΔT of 125°C.

Heat exchangers joined with:	Log. average of cycles to failure
Copper	2 600
MBF-51	600
AlfaNova	2 100

Discussion

The pressure fatigue resistance was extraordinarily good for the heat exchangers produced with the AlfaFusion technique, significantly better than both the copper brazed and the nickel brazed units. The main reasons are

1. The different sizes of the joints. The joint produced with AlfaFusion and the copper-based braze fillers are quite similar in size, but joints brazed with nickel-based filler are smaller. Comparing the nickel-based filler with the AlfaFusion joints, the AlfaFusion joints fills wide gaps better and has not shown any erosion on the plate material, which makes it possible to produce larger braze joints.
2. The braze joints themselves have different fatigue resistance. Copper-brazed joints are softer and have lower fatigue resistance than the harder iron-based AlfaFusion joints. Also the great interaction between the base material and the filler, creating a joint similar to a welded joint, increases the fatigue resistance of the AlfaFusion joint.
3. The shape and amount of brittle phases that form due to the presence of melting point depressants, including Si and B. It has not yet been fully verified but it appears that the amount and/or shape of brittle phases in the AlfaFusion joints have a less severe impact on the joint strength than for the joints brazed with the nickel-based filler that were tested.

The resistance to temperature fatigue for the AlfaNova was slightly lower than for the copper-brazed but significantly better than for the nickel-brazed. It should also be noted that the AlfaNova has been approved for use up to 550 °C as compared to 225 °C for copper-brazed and 400 °C for nickel-brazed.

CORROSION

The corrosion property of a plate heat exchanger is a dominant feature when evaluating its utilisation in different process media and applications. In case of the traditional BPHE or the novel TLP bonded AlfaNova, the evaluation of the combination of plate material and filler is required to enable an accurate estimation of its corrosion behavior. Furthermore, effects relating to joint design and heat treatment procedure have to be considered.

Copper and silver-copper-zinc based braze fillers are widely used to join stainless steel for applications in aqueous environments. However, these fillers' shortcomings in alkaline environments, in organic and inorganic acids as well as in hygienic applications have impelled the use of nickel based braze fillers, fully welded structures or gasketed heat exchangers.

Experimental Techniques

The plate material used in the corrosion experiments was stainless steel type EN 1.4401 with a thickness of 0.4 mm, see Table 1 above for its nominal chemical composition. The nominal chemical compositions of fillers other than AlfaNova (listed in Table 1) are shown in Table 2.

A so-called Waffle test specimen consisting of two corrugated circular plates was brazed respectively fused together in four contact points with the filler as seen in Figure 3. The sample was used for immersion testing and corresponding weight loss measurements. The amount of filler in each Waffle specimen was approximately 0.2 g.

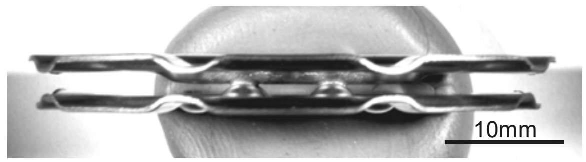

Figure 3 Side view of Waffle test specimen.

Table 6 Test solutions.

Solution	Conc.	Temp.
Ammonium hydroxide (NH_4OH)	35 w%	80 °C
Sodium hydroxide (NaOH)	40 w%	80 °C
Nitric acid (HNO_3)	20 w%	80 °C
Sulphuric acid (H_2SO_4)	20 w%	40 °C
Chlorides (NaCl)	300 ppm	80 °C

The Waffle samples were weighed and subsequently exposed in 200 ml solution for 14 days, see Table 6 for specific conditions. After exposure the samples were washed with distilled water and dried before the weight measurement. Also samples of the plate material without filler were exposed to the solutions as a reference. A selection of the exposed samples was metallographically prepared and examined in the light optical microscope.

Results

The results of the weight loss measurements are shown in Figure 4 through Figure 8. The results are presented as absolute weight loss, as the irregular geometry and chemical composition of the test specimen rendered conversion into a corrosion rate impossible. Consequently, the weight loss measurements primarily have comparative value.

It is seen that all fillers, except copper, are resistant to general corrosion in ammonium hydroxide. Similar behaviour is observed for nitric acid. Nitric acid is an oxidising acid and boiling concentrated nitric acid is used to evaluate the susceptibility to intergranular corrosion, the so-called Huey test. However, the metallographical evaluation of the AlfaNova specimen found no evidence of intergranular corrosion.

The highest corrosion rates were observed in sulfuric acid. All filler specimens have weight losses between 0.6 and 1.0 g. The metallographical evaluation found indications of general corrosion and intergranular attacks. Despite the relatively large variations in alloying elements like iron, nickel and chromium and in the melting point depressants silicon, boron and phosphorus, the results from the Waffle specimens showed that only minor differences exist in corrosion resistance, excluding copper of course, between the tested fillers in the selected solutions. High amounts of nickel in the nickel-based fillers should be advantageous in the dilute sulfuric acid solution. This was however not observed. No corrosion is observed on the reference material.

The complex microstructure that originates from the metallurgical interaction between the filler and plate material dictates that corrosion tests involving active fillers always should be accompanied by microstructural examination by light optical microscopy. "Insignificant" weight losses may involve local deterioration that only can be determined by cross sectional microscopy.

Minute corrosion was observed on all specimens including the reference material exposed in sodium hydroxide. No weight loss was observed on any of specimens exposed in the neutral 300 ppm chloride solution. The metallographical examination of the specimens did not show any signs of corrosion.

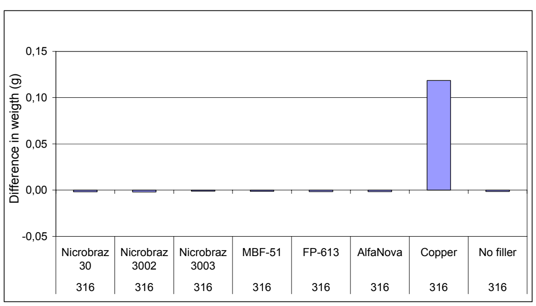

Figure 4 Ammonium hydroxide 35% at 80 °C.

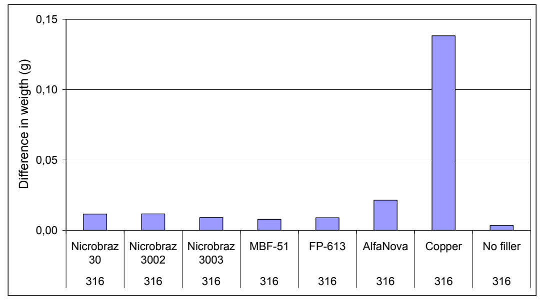

Figure 5 Nitric acid 20% at 80 °C.

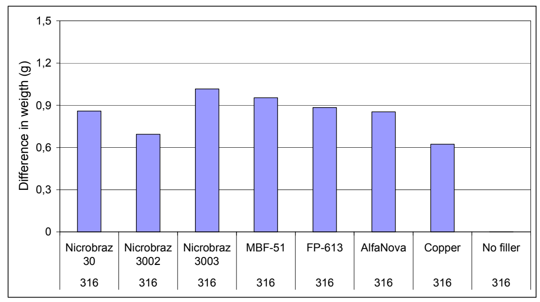

Figure 6 Sulphuric acid 20% at 40 °C. Please observe scale on the value axis.

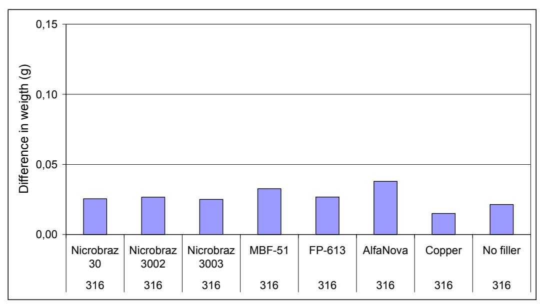

Figure 7 Sodium hydroxide 40% at 80 °C.

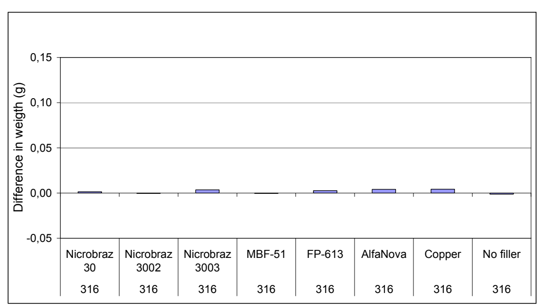

Figure 8 Aqueous chloride solution 300 ppm at 80 °C.

CONCLUSIONS

Extensive testing shows that the AlfaNova is superior to nickel-brazed PHE:s in terms of mechanical properties such as pressure and temperature fatigue resistance. From a corrosion point of view it is on the same level in the acid and alkaline environments that have been tested. Compared to copper-brazed units, AlfaNova offers better high temperature performance and a wider applicability in terms of chemical compatibility. Corrosion-wise, AlfaNova is more resistant to ammonium hydroxide and nitric acid than the copper-brazed units. Finally, compared to all-welded compact heat exchangers, the AlfaNova is a more cost-efficient alternative as well as much more resistant to pressure fatigue.

Within one year from its launch, several industrial customers have already installed and commissioned AlfaNova in a wide range of applications. The good corrosion resistance makes it suitable for a large variety of application areas. Its resistance to ammonium hydroxide will translate into refrigerant applications containing ammonia.

Nitric acid and sodium hydroxide are used as cleaning agents in sanitary and pharmaceutical industries and the minute corrosion rates that were observed in these chemicals makes the AlfaNova suitable even in these types of applications. The resistance to pitting corrosion in a 300 ppm chloride solution at 80 °C will enable utilization in most process water applications. Finally, it must be assumed that the AlfaNova will be suitable for a large range of hydrocarbon applications were gasket-free solutions are required.

With the AlfaNova a new class of plate heat exchangers is defined where the stainless steel plates are bonded together with TLP bonding. The exchangers exhibit a unique set of properties that sets them aside from the copper and nickel brazed PHE:s as well as from the all-welded compact heat exchangers. This is achieved already with the first generation exchangers, which were originally designed for brazing with nickel foil. With a bonding geometry optimized for the TLP bonding technology, it is envisaged that possibilities are offered that traditional brazing is not capable of, bordering on activated diffusion bonding resulting in further increases in mechanical and chemical properties.