Fully Welded Ceramic Components for High Performance Heat Exchangers and Flow Reactors

Sintered silicon carbide (SSiC) offers excellent properties for high performance devices in chemical and pharmaceutical process industry as well for solar receiver modules: high mechanical and corrosion resistance combined with excellent heat conductivity.

High-tech ceramics like sintered silicon carbide (SSiC) have high potential to boost the performance of devices in chemical process technology. Due to the excellent resistance against corrosion and superb heat conductivity, SiC increasingly replaces components made of conventional materials in chemical pumps and heat exchangers. Plate heat exchangers and flow reactors represent new generations of high performance devices. Key component are fully welded plate packages serving as hermetic pressure vessels. Advantages include extended life and reduced maintenance costs. The material stability is such that applications even in a high temperature range of 1000 °C and related applications in the area of energy generation like solar power plants can be expected.

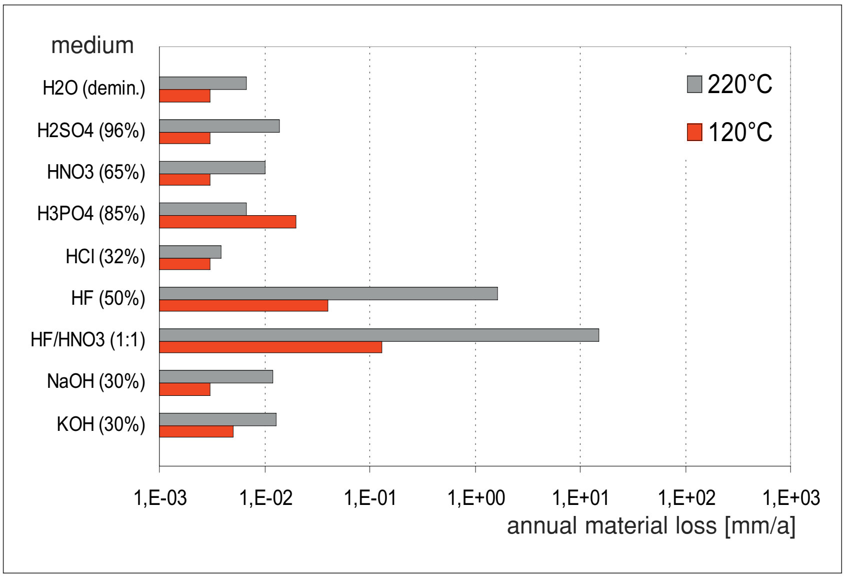

Fig. 1
Corrosion resistance of EKasic® C silicon carbide in different media. Material loss data determined with autoclave test series

Introduction

At temperatures of around 200 °C, hot sulphuric acid and concentrated caustic soda become highly corrosive. During manufacturing or recycling, the equipment is exposed to demanding corrosion, especially reactors and heat exchangers exposed to peak temperatures. Metallic devices made of stainless steel and nickel alloy suffer considerably and show a limited economic life-time, particular at elevated temperatures or medium concentrations. The damage is marked by extensive pitting corrosion. Ceramic components made of silicon carbide (SiC) help extend the life of mechanical seals in chemical pumps and tubes in heat exchangers. Particularly coarse-grained silicon carbide material grades have been verified to show outstanding performance. ESK manufactures plate heat exchangers and flow reactors based on coarse-grained EKasic® C. The material provides excellent resistance against acids and alkalis even under extreme conditions. Fig. 1 shows the annual material loss, which in most cases does not even exceed 0,1 mm per year. With wall thicknesses in the range of millimeters, the expected life time extends over several years. Since 2008, devices are used in production and prove their value. Below are initial results from long-term production cycles with plate heat exchangers.
Moreover, high tech ceramic EKasic® C provides an additional advantage. ESK has

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Heat exchangers, flow reactors, solar receiver modules, sintered silicon carbide (SSiC), welding, chemical industry, pharmaceutical industry

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developed a special diffusion welding process for welding stacks of plates manufactured from EKasic® C. The welding of full plate packages result in hermetic, gas tight monoliths able to resist high pressures and high temperatures. Those monoliths create new generations of process equipment with ceramic pressure vessels as key components. Fully welded plate heat exchangers and monolithic flow reactors are examples of these new generations. Monolithic plate heat exchangers do not contain flat gaskets and are inherently safe against leakage. Silicon carbide flow reactors are designed to speed up processing routes and diffuse considerable amounts of heat created in highly exothermic reactions. Both types are designed to increase safety and to extent the application boundaries of devices used in chemical process technology. This article presents different designs and key applications.

Welding of silicon carbide

The welding of silicon carbide based on ESK technology converts multiple stacks of plates into monoliths free of interfaces. Because of the inert nature of the material, the welding process requires plate formats with conditioned surfaces and high temperatures. A special feature is that the plates can have almost any channel configurations. Internal manifolds can be integrated into the plate design and stacking sequences can be chosen depending on the targeted overall reactor design.

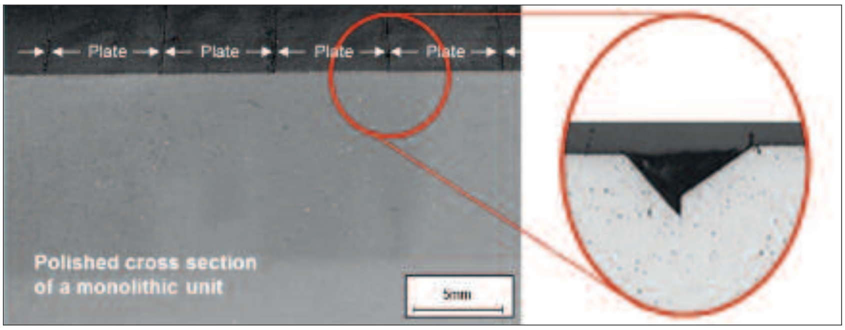

Fig. 2
Cross section of a fully welded silicon carbide monolith.
No interfaces or second phases are present at the former joint

Also, the welded monolith does not contain secondary phases as demonstrated by the cross section in Fig. 2. Basically there is neither a possibility for corrosive media to migrate nor to attack weak interfaces. Both form the basis of a long economic life time and the device's safety.

Applications

SiC-plate heat exchangers for acid and alkali processing

Overall, the general concept of ESK's ceramic plate heat exchangers do agree with those of conventional plate heat exchangers. A metallic frame – either steel or stainless steel – is used to hold a ceramic plate packages or the welded monolith. The ceramic components are tightened by tie bolts and disc springs. Flanges are lined with PTFE in order to avoid steel components having contact with aggressive media. A photograph is shown in Fig. 3.

The monolithic plate heat exchangers are particularly interesting for processing of critical media that is dangerous to the environment like sulphuric acid with concentrations below 97 %. The high safety standards require fully welded systems. Since several years, devices are in operation with negligible amounts of corrosion. From time to time, cleaning from fouling scales is required on the service side. This is easily accomplished by using aggressive media.

The liquid processing plates have a channel pattern that opposes the media in order to meander and create turbulences through channel wall openings. An example for two different sizes is shown in Fig. 4. Advantages include high efficiency, small pressure losses and good swirling even with high viscosity media like sulphuric acid. Due to the high thermal conductivity of the high-tech ceramic and par-

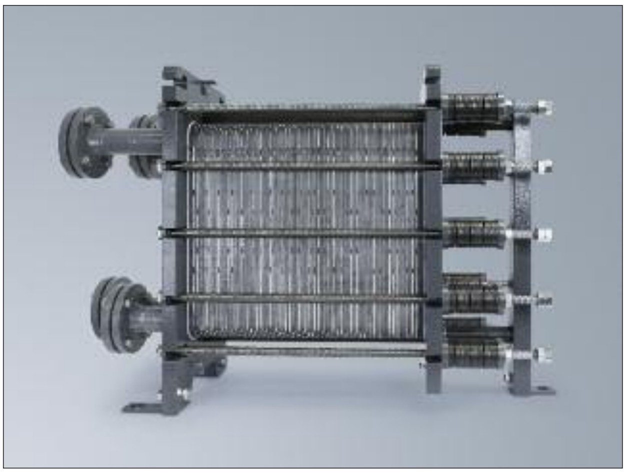

Fig. 3
Silicon carbide plate heat exchanger
of type B500

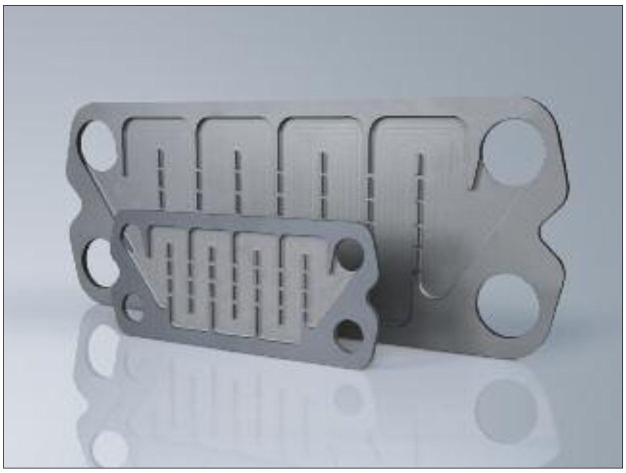

Fig. 4
SiC plate formats B500 and B260 with a
channel pattern optimized for liquids

Fig. 5
EKasic® C heat exchanger plate after service for 2,5 years in caustic soda (50 % concentration) at approx. 170 °C. Plate surface with product deposits (white) and nearly virgin surface

ticular flow patterns, the ceramic plate heat exchanger exhibits an unusually high specific heat transfer performance exceeding values of 8000 W/m^2·K. The standard channel height of 3,5 mm provides for small particles and intrinsically reduces danger of blocking. The devices can be applied to temperatures between –30 °C and up to +200 °C at pressures of up to 16 bar.

Depending on thermal load and specified pressure loss, the ceramic plates and the stacking sequence within the plate package can be adjusted to create a multiple pass flow. The plate package can either be fully welded, semi-welded (any two plates get welded) or gasketed with PTFE flat gaskets. The gasketed version does not provide the maximum degree of safety but has the advantage of being dismountable. Fig. 5 shows a photograph of a dismounted plate package after use for 2,5 years in hot caustic soda (approx. 170 °C). The medium with a concentration of 50 % did not lead to visible material removal. Aside from white-colored material deposits the surfaces looks brand new.

SiC-plate heat exchangers for media with high particle loadings

The ceramic plate heat exchangers are also a perfect tool for cooling suspensions with solid loadings. Usually, mineral particles wear out surfaces rapidly and cause debris and metallic impurities within the media. The latter is an issue when processing hard particles like glass suspensions or hard particles during milling treatment of technical ceramics. Due to the excellent hardness of the plate material the debris formation is small in SiC plate heat exchangers. Several devices are in operation on the periphery of glass mills and even on silicon carbide mills. Long track records have demonstrated that the solid loadings within the media that run through the mills could be increased without running the mantle material at critical temperatures.

The high efficiency even with high viscosity suspensions allows building compact,

Fig. 6
Modular flow reactor with six exchangeable monolithic reactor modules made of EKasic® silicon carbide

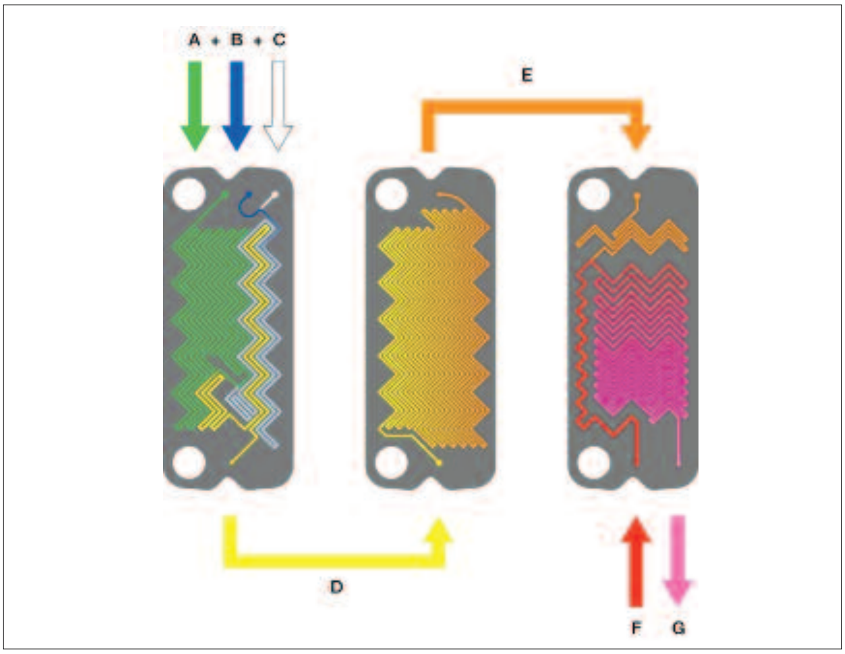

Fig. 7
Schematic of the interaction of mixer modules and residence and quench modules within a flow reactor

easy to integrate devices within the mill systems. With 0,5 m^2 of heat exchange surface, a power transfer of 50 kW is possible in case of high solid silicon carbide loadings.

Flow-reactors for drug synthesis

Flow reactors represent an emerging group of new devices designed for the continuous production of fine chemicals and pharmaceuticals. Differentiating features of these reactor concepts are the reaction chambers with particularly fine structured channel geometry and favorable surface-to-volume ratios. The key advantage is a continuous, safe and flexible production with tailored residence time.

ESK manufactures flow reactors from sintered silicon carbide, especially for enabling users to feed highly concentrated media for synthesis. The already mentioned superb heat conductivity of SiC assures that fast reactions with excess heat can be run in a controlled manner without formation of hot spots.

SiC-flow reactors are suitable for instance for neutralization reactions wherein the media does not require much dilution. Beside sufficient corrosion resistance, the ability to diffuse heat efficiently and resistance against hydraulic pressure are required. Key advantages are a reduced amount of waste water and heat recovery via the service medium.

For the manufacture of the devices, ESK uses a proprietary welding technology. Plate packages consisting of heat exchanger plates and reactor plates are welded to give hermetic SiC monolith. The modular concept allows building reactors with different functions in a single set-up and to drive a complete synthesis process starting from mixing to curing and final quenching. Fig. 6 shows a flow reactor with six monolithic reactor modules arranged in sequence. Fig. 7 demonstrates the interaction of a sequence of modules.

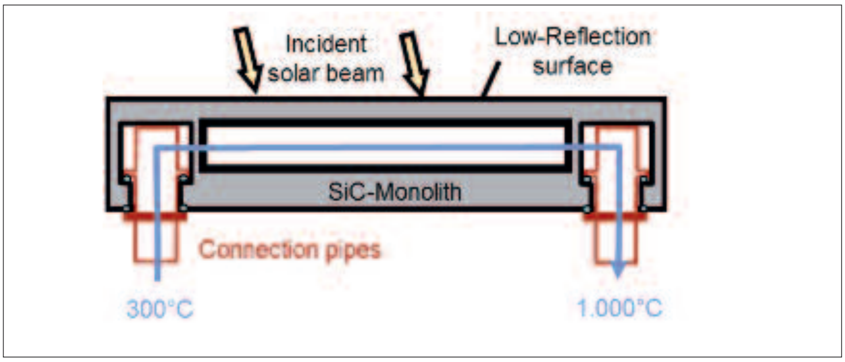

Fig. 8
Concept for solar receiver module based on fully welded SiC plate packages

To ensure full scalability of new reactions ESK cooperates with *Chemtrix B.V.*, a specialist for flow reaction design and laboratory scale reactors.

So the fine chemical and pharmaceutical industry has got the opportunity to develop new reactions based on flow reaction technology in the lab and to easily transfer them into efficient production processes.

Application solar power plants

Concentrated solar power (CSP) is an emerging technology helping to meet Europe's target of zero emissions in 2050 with its electrical supply system. Solar power plants are believed to play a key role as the overall efficiency is comparably high among the different CSP systems [1]. The efficiency still has potential for improvement. The use of ceramic components as receiver components is becoming essential for construction. The solar receiver is the key component of the power generation system. Air is running through the receiver and is heated through the solar radiation concentrated on the receiver's surface. Highly desirable is the transition to a pressurized system required to operate safely at 1000 °C. Current activities are focusing on so-called volumetric solar receivers wherein the air is pressurized [2].

Novel approaches include equipping the solar receivers with fully welded ceramic receiver modules with the aim of boosting the outlet temperature from 800 °C to 1000 °C while operating at 16 bar. These pressurized high temperature systems would enable incorporating a gas turbine for the generation of electricity while still improving the overall efficiency.

A concept based on fully welded ceramic solar receivers is in development and has already been presented elsewhere [3]. The central unit is a SiC-monolith with a single chamber and internal channels guiding the air towards the hot surfaces. A sketch is show in Fig. 8. Using the same welding technology as for heat exchangers and flow reactors, the monolith is manufactured from individual plates with a specific channel design and internal manifolds to which flanges are attached. Manufacturing by welding individual plates allows achieving a full ceramic monolith with internal channels having an optimum design for heat transfer, pressure loss and pressure resistance. Advantages over competing systems include high mechanical stability and heat conductivity even above 1000 °C and minimum complexity with increased system safety.

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