Modular microstructured reactors based on new manufacturing techniques

It is a major aim of the CoPIRIDE project to provide the European chemical industry with technical solutions which enable the application of intensified, continuous processes. Process intensification is an acknowledged possibility to reduce the production costs of chemicals and thus to increase competitiveness. Amongst others, process intensification can be achieved as result of the application of Novel Process Windows like accelerating reactions by using higher temperatures or concentrations. Also the development and use of catalysts is a way to increase productivity. However, all this needs adequate reactors which allow for handling the increased requirements with respect to heat and mass transfer.

Microreactors have a huge potential to control even highly exothermic and fast reactions due to their high ratio of surface to volume and small channel dimensions. They are also well suited for the application of highly active heterogeneous catalysts. To date, microstructured reactors are broadly applied in lab scale and in numerous cases up to pilot and production scale for the intensification of chemical processes. Currently available techniques are well elaborated to enable the commercial manufacture of laboratory reactors in small series and of pilot reactors.

However, there is still a lack of appropriate and costefficient manufacturing techniques applicable for microstructured devices which are suited for the high throughputs of production scale. Currently, metal and especially stainless steel plates are microstructured using wet chemical etching or mechanical machining processes. Both techniques are comparatively expensive, limited in size and less suited for an economic mass production.

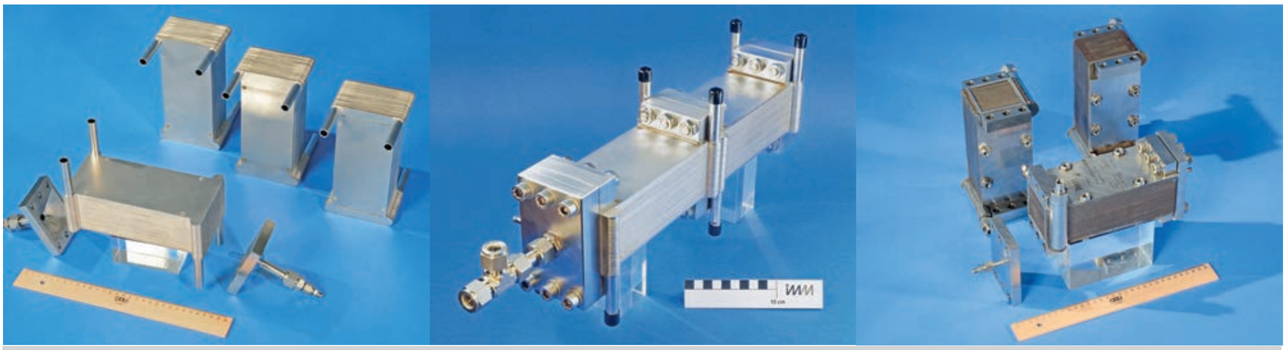
In CoPIRIDE, these restrictions will be overcome using a new manufacturing approach in which microstructuring by roll embossing plays a central role. Furthermore, a reactor manufacturing strategy is followed which enables achieving a large variety of different reactor modules based on a small number of manufacturing tools and steps. This allows the adaptation of the reactor design to a broad range of process needs like throughput, residence time, reaction conditions like pressure and temperature, heat and mass transfer, involved phases, and use of heterogeneous catalysts. Size and composition of the reaction modules can be varied by changing the structured width, the length and number of plates. The appropriate joining technology of the stacked plates can be chosen, e.g. laser welding, vacuum brazing.

Whereas vacuum brazing gives high pressure stability, widely independent of size, it is not possible to insert a catalyst prior to brazing, due to the high temperatures applied. However, laser welding with its controlled heat input allows for catalyst insertion prior to welding, but the achieved pressure stability depends on the device size. Combination of different reactor modules opens additional flexibility.

The advanced development status of such modular microstructured reactors made by using the new manufacturing techniques is demonstrated by their implementation in pilot plants. These encouraging results base on joint efforts of Wetzel Company (roll embossing), Laserzentrum Schorcht (laser cutting and welding), and IMM (coordination, reactor concepts and design, vacuum brazing).

For further details, please see also the reports of the CoPIRIDE partners in this newsletter.

Dipl.-Ing. Ulrich Krtschil, Institut für Mikrotechnik Mainz GmbH, acts as Technical Project Manager and leads Work Package 3 (Modular Microreactor Design, Fabrication, and Testing). As a chemical engineer, he had three decades experiences from work in industry before he joined IMM in 2004.



Vacuum brazed (left) and laser welded (right) reactor modules comprising plates microstructured by roll embossing, threefold modular test reactor (mid).

The research leading to these results has received funding from the European Community's Seventh Framework Programme [FP7/2007-2013] under grant agreement no. CP-IP 228853-2

Microstructuring of technical functional surfaces on stainless steel strip (metal plates) by means of efficient rotary embossing

The WETZEL Processing Group is one of the most accomplished and innovative groups of companies in the printing and embossing industry. The headquarters of the group is at WETZEL GmbH in Grenzach-Wyhlen/Germany. Another subsidiary, WETZEL Sp.z.o.o. located near Warsaw in Poland, supplies the central European market with printing forms. Along with rotogravure cylinders and flexographic sleeves, WETZEL also manufactures embossing rollers and embossing machines which are used in various industries including the packaging, furniture, aerospace and automotive sectors as well as for decorative and architectural applications in the construction industry.

As part of various research and development projects, a multi-functional test line was installed at WETZEL in Grenzach-Wyhlen.

As well as the special coating applications and the previous embossing applications, this system was used as the basis for developing an efficient rotary embossing process for manufacturing micro-structured stainless steel strip in the ongoing CoPIRIDE research project. These structured plates are, in turn, used in microreactors deployed in the chemical industry.

The trial system called "APOLLO" has all of the technologies needed to develop new application technologies close to the production line as well as to test the requirements of the new functional surfaces for the manufacture of microreactors using new manufacturing methods.

Michael Streuber, Wetzel GmbH, has broad experience of embossing technology and rolling process engineering and is within CoPIRIDE task leader of Workpackage 3.2 (new manufacturing techniques by roll embossing and soldering)

Combining digitalisation processes with the most modern engraving processes and the latest laser technology has enabled WETZEL to produce technical functional surfaces and engrave the finest microstructures in surfaces.

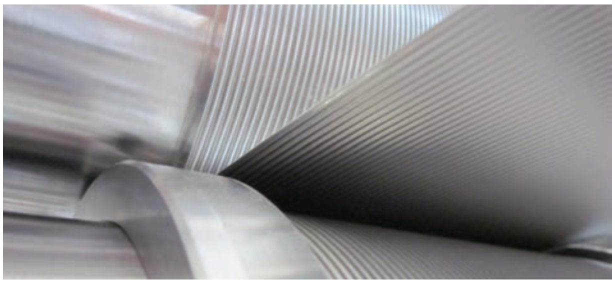
The production of micro and nano structures (e.g. the sophisticated skin resembling that of a shark with a special 3D effect or the lotus flower or light refraction effects) were researched in various projects for renowned clients in the same way as the use of ultra-fast phenomena.

In particular re-creating bionic surfaces on rotary tools can be tackled with the new laser technology.

The ability to test the transfer of the functional surfaces to different materials (such as stainless steel, aluminium, copper, plastics, films, cardboard, paper etc.) on the test line is the basis of a new complete process chain for the possible market launch.

During the course of the CoPIRIDE project, WETZEL GmbH exploited its extensive technical know-how to develop the manufacturing process for micro-structuring the process-relevant reactor plates made from stainless steel strip, together with the innovative and reproducible structure parameters for this. Different to the previously used reactor plates which were produced in line with present-day technology using conventional etching technology, at WETZEL the manufacturing process is examined by means of rollers in a special embossing calender which was modified/re-developed as part of the CoPIRIDE project. This in-house developed embossing calender was incorporated in the "APOLLO" test line in order to also test the required complete manufacturing process from coil to coil.

The focus here was on the standardisation and development of the efficient manufacturing process for microstructured reactor plates from small batches through to mass production.



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Laser welding for stacked plate reactors

Figure 1: P. Schorcht (left) and P. Weimar (right) in front of the fibre laser system inspecting a CoPIRIDE reactor

The main task for Laserzentrum Schorcht Company within the CoPIRIDE project is the development of an industrial laser welding technology for microstructured stacked plate reactors comprising thin plates of less than 0.2 mm. This includes the development of an appropriate method for stacking different frames as well as thin flat and corrugated plates prior to the laser welding. These laser-welded stacks can be used, for example, as heat exchangers or modules of microstructured reactors. In addition to the development and provision of the technology, Laserzentrum Schorcht Company is particularly interested in the economics of the manufacturing process. Here the goal is limiting the manufacturing time, e.g. maximizing the speed of laser welding, whilst ensuring high quality.

For this reasons, an advanced fibre laser is applied. This plant (*Figure 1*) is equipped with very fast linear motors, providing accelerations and velocities of 10 m/s and 10 m/s, respectively. The accuracy of the axes is about 5 µm. The fibre laser has 2000 W of power and two changeable fibres with different core diameters.

In principle, laser welding of stacked plate devices consisting of conventionally, e.g. mechanically or wet-chemically etched, micro-structured plates is an established technology. However, laser welding of the comparatively thin plates of microstructured reactors based on the new manufacturing techniques developed within CoPIRIDE is challenging and requires further development. Thus, initial weld tests with thin plates were carried out and the achieved weld seam quality was investigated (see *Figure 2*). In a next step, simple stacks of plates microstructured by roll embossing of only 0.15 mm thick high-grade steel strips were welded applying the determined best suited welding parameters. With these experiences, several varieties and sizes (up to 60 mm structured width) of microreactors comprising plates micro-structured by roll embossing were stacked and joined by laser welding (see *Figures 3 and 4*). Currently, laser welded reactors comprising roll embossed plates with 150 mm micro-structured width are in manufacture. A further enlargement of the reactor dimensions is planned.

The Laserzentrum Schorcht Company offers contract manufacturing in laser materials ranging from technological development to full production. The equipment consists of 12 laser systems whereof four are also used for laser cutting.

For example, large and small heat exchangers, ball bearings with a diameter of 3 mm, or surgical instruments were laser welded and often afterwards labelled. Laser cutting of any contour in tubes up to 2.60 m long and up to a 400 mm in diameter, flat bed cutting up to 1.50 x 3.00 m and especially micro-cutting are provided.

Dipl. Phys. Peter Schorcht studied Physics in nonlinear optics at the Friedrich Schiller University Jena. He was involved in the development of different lasers, before he founded his own company, the Laserzentrum Schorcht GmbH, in 1995.

Dipl. Ing. Peter Weimar studied precision engineering at the University of Applied Sciences Jena. Within the Laserzentrum Schorcht, he is responsible for projects of laser material processing requiring highest precision and acts as project manager. In CoPIRIDE, he is also the task leader for large-size laser welded microreactors.

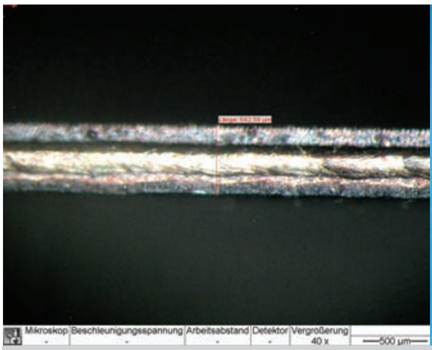

Figure 2: First welding tests with two thin plates

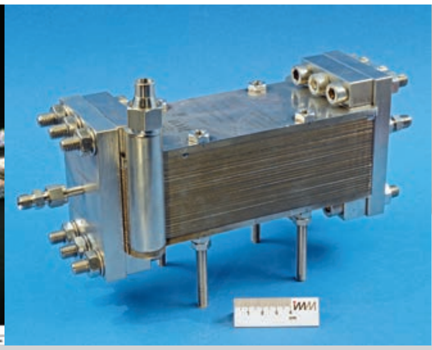

Figure 3: Laser welded reactor comprising roll embossed plates

Figure 4: Two stacked foam microreactors in different sizes

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