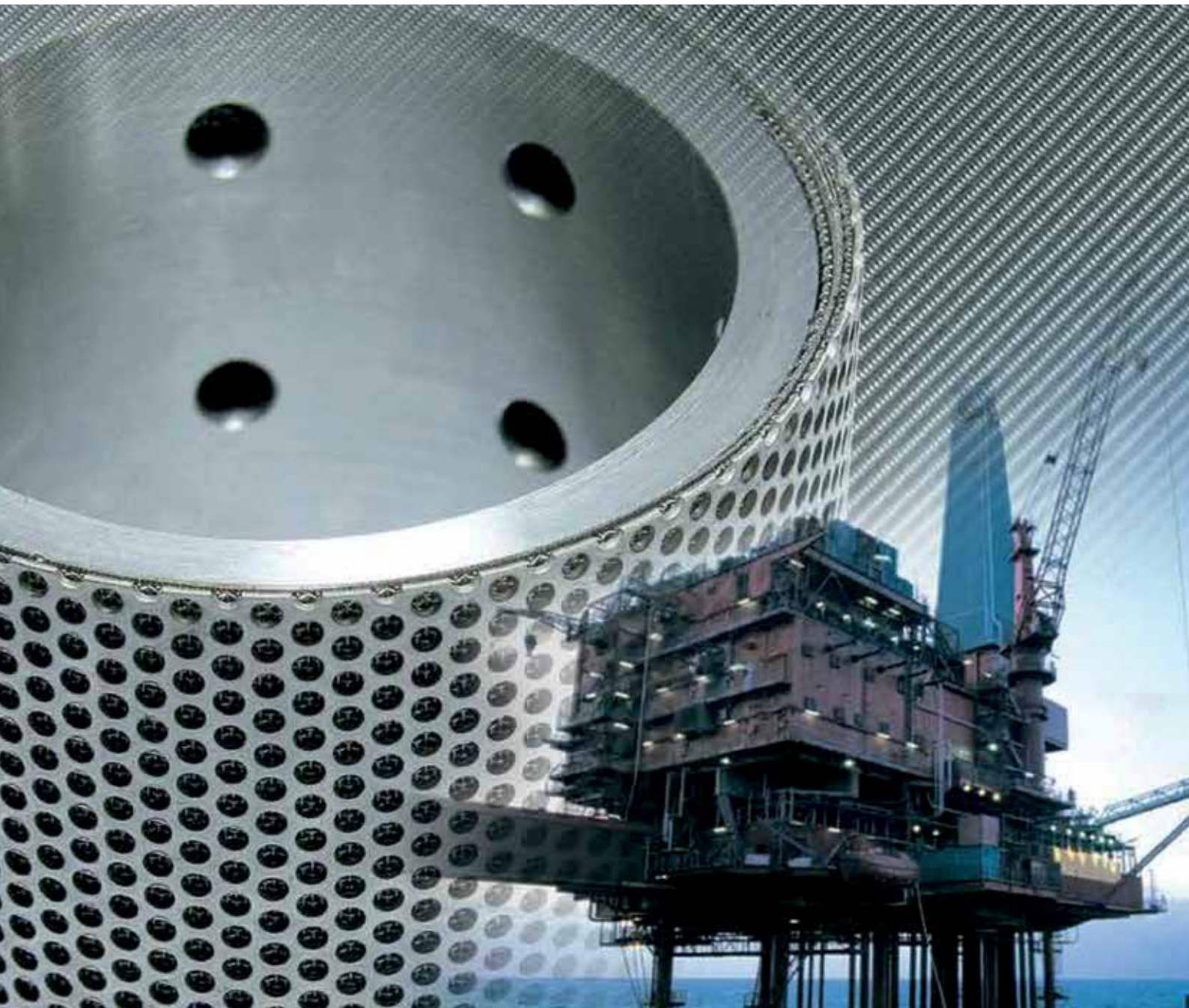


PREMIUM WOVEN SAND CONTROL SCREENS FOR OIL AND GAS EXPLORATION

STANDARD METAL WIRE MESH + PREMIUM METAL WIRE MESH (RDTW)



PROVIDING SPECIAL MESH SOLUTIONS



State-of-the-art weaving facility

In search of new oil and gas sources the use of GKD high performance wire mesh screens with defined mechanical, physical and chemical properties are required.

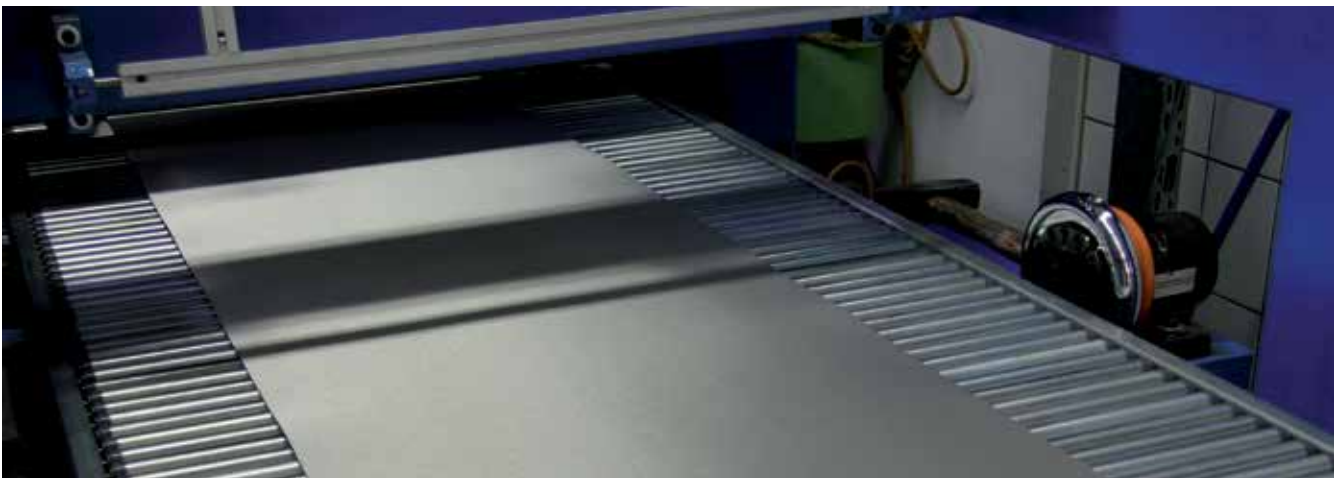
New oil and gas fields have been identified. The tools for exploring those fields are exposed to various rock formations and aggressive media which reacts with the equipment being used. Sand screens or well screens are used in the Petroleum Industry to keep out particles from production fluids. The Well screens are tubular in shape and include a perforated base pipe. The screens are used where fluids enter a production stream and have to pass through the woven filter layers. In that context of filtration, our Premium woven sand control screens prevent particles of the desired micron sizes and larger from passing through the screens. GKD produces many different weave designs. The best mesh choice usually considers pore size stability, robustness, strength and permeability. That's why we recommend RDTW meshes (Reversed Dutch Twilled Weaves).

Besides RDTW meshes we manufacture various types of weave patterns as well. Important to know is the fact that weaving of sand control screens and the following processing is only done in Germany.

THE ADVANTAGES OF GKD RDTW MESHES:

- Stable pore structures
 - High flow rates
 - Cleanability
 - Excellent retention rates
 - Extremely durable with outstanding burst and collapse resistance values
 - Available in materials 316 L, Incoloy 825 and Alloy 20
 - Ranging in pore sizes from 60 μm to 600 μm
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OUR TECHNOLOGY AND MANUFACTURING EXPERTISE



Exemplary rectangular sand screen panel

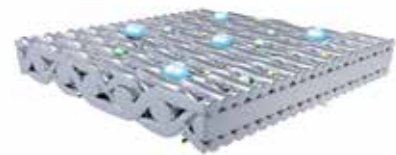
OUR TECHNOLOGY AND MANUFACTURING EXPERTISE – YOUR ADVANTAGE FOR PREMIUM QUALITY

Our latest state-of-the-art production facility and wide range of weaving machinery provides specific filtration meshes regarding pore sizes and durability characteristics as required for the application.

Depending on customer’s requirements, we are able to modify existing woven wire meshes, or develop, and design totally new woven wire meshes. While some customers and applications ask for very robust meshes resisting high burst- and collapse values, other applications call for optimizations in permeability or reduction of costs.

The above various requirements can be determined within a very short period of time by using the GKD in-house software tools like the GeoDict® or some FEM solver. The chart on the right only shows an extract of available sand control meshes and intermediate sizes regarding openings which are available.

Extract of available sand control meshes



Pore sizes [µm]	Porosity [%]	Air permeability at 200 Pa [l/m²/s]	Permeability [D]
60	49	1864	24
100	50	2091	28
125	48	2320	34
150	50	2460	35
175	52	2260	49
200	50	2350	55
225	52	2830	53
250	56	3360	53
275	57	4080	59
300	59	4720	65
350	64	5840	63
400	65	5940	101
600	66	6140	89

3 POST WEAVING PROCESSES

GKD'S MANUFACTURING STEPS THAT LEAD TO PREMIUM QUALITY



1. Cleaning



2. Heat Treatment



3. Finishing

TO AVOID CORROSION PROBLEMS GKD IS USING THE FOLLOWING AFTER WEAVING EQUIPMENT:

1. CLEANING (left)

To remove dirt and oil from the screens, it is important to clean the screens after weaving in a controlled continuous running process. For that reason, GKD has latest state-of-the-art equipment in place to protect the high grade metal to remove dirt and oil from the screens, cleaning is absolutely necessary.

2. HEAT TREATMENT (center)

Modern heat treatment facilities are available in-house. We typically treat our screens in one of our continuous furnaces. Our furnaces are approved to meet the strict requirements of API Spec. 6A that ensures homogeneous material proper-

ties for all sections which help to avoid types of corrosion. Details of the specification NACE MR0175 with a narrow tolerance of hardness and strength have to be respected. A reliable process control in all steps of production is necessary to secure the chemical properties.

3. FINISHING (right)

Our optical control equipment ensures 100 per cent control of all pores in the screens. High power LED line light is mounted below an inspection table which has a slot that covers the complete width of a sand control panel. Above that slot inspection cameras are placed. A transmitted light method is used. Each panel is slowly pulled along the inspection table, so that 100% of all pores (in length and width) inside the sand control screen panels are checked for any irregularities (e.g. weaving faults that increase the opening).

1. CLEANING

THE POWER OF ULTRASONIC CLEANERS



To provide our premium sand screens without any signs of dirt is a necessity as well. Dirt, dust and oil might still remain on the surface of wires after the weaving process. Therefore GKD has several continuous cleaning devices in place which use the power of ultra-sonic.

Our ultrasonic cleaning devices use so-called cavitation bubbles induced by high frequency sound usually > 20 kHz to agitate the cleaning solvent. Of course not plain tap water is used, but an appropriate attuned and warm cleaning solvent to intensify the cleaning mechanism. Depending on special customer requirements, our cleaning solution may also contain ingredients designed to make ultrasonic cleaning more effective by e.g. a reduction of surface tension.

The agitation produces very high forces on contaminants adhering to the surface of the wires and pores inside the sand screens are penetrated and cleaned as well. Our cleaning devices use multiple ultrasonic heads to ensure an overall removal of dirt in any location of the wire mesh.

To minimize the consumption of water for environmental reason, GKD monitors multiple times e.g. the ph-value, water temperature and degree of contamination.

REASONS FOR US CLEANING:

- To avoid galvanic corrosion
 - To secure an efficient optical inspection subsequently
 - Necessary for the heat treatment process afterwards
-

2. ANNEALING

SOME STATISTICS ABOUT THE EXISTING GRAIN STRUCTURE



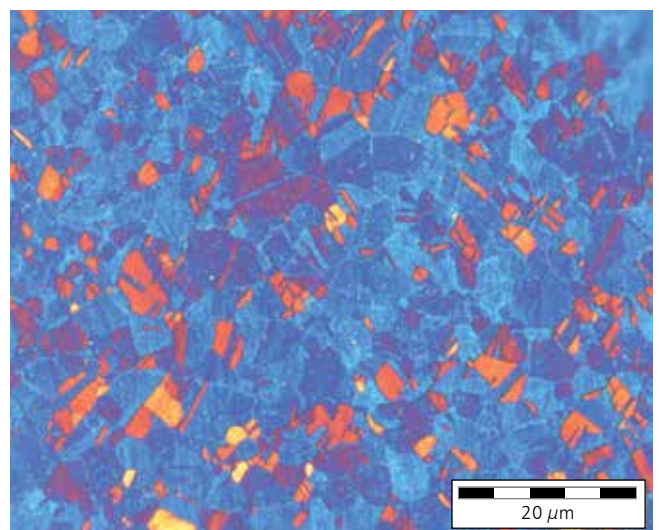
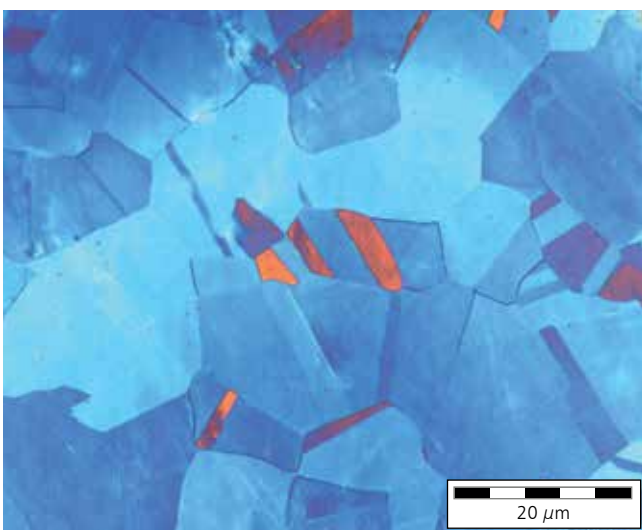
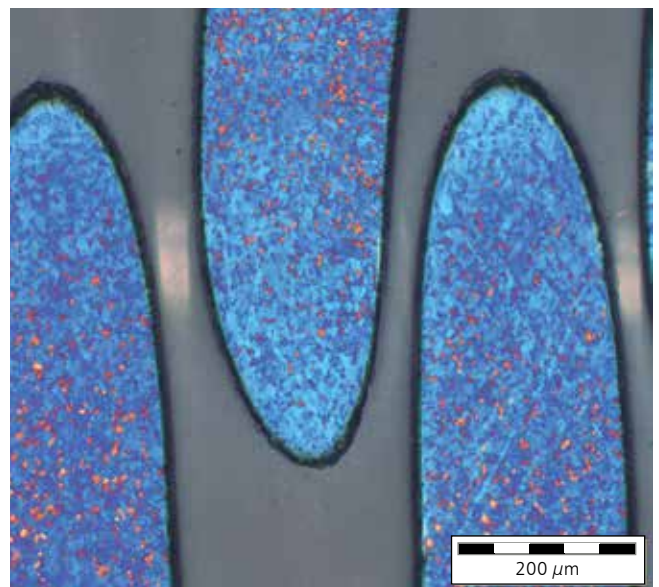
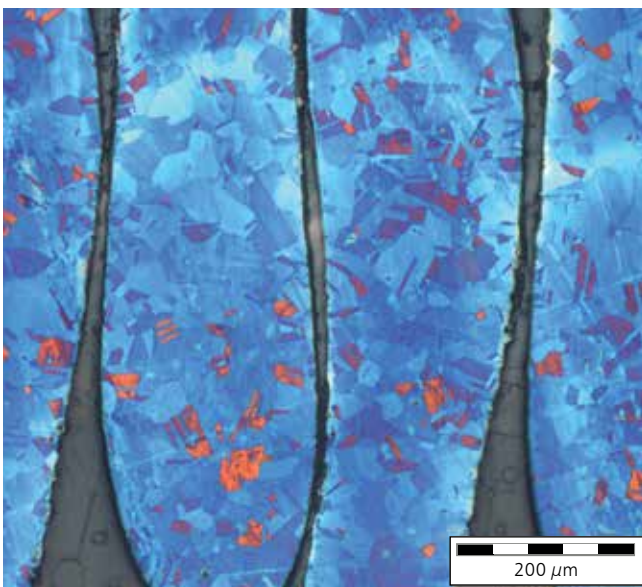
In-house API spec 6A compliant heat treatment

We only use heat treated wires for the weaving process. Depending on the woven wire mesh construction, the wires get strongly cold deformed during weaving which results in possible critical stresses. Important to know is the fact that stretching the wires while weaving is not that critical as local compression (as shown in the left picture on page 10). Therefore we use our two in-house continuous annealing furnaces which operate according to API Spec 6A. Our annealing process consists of heating the material up to a specific temperature and holding it long enough for the car-

bon to go into solution. After this, our wire mesh products are quickly cooled to prevent the carbon from coming out of solution. By annealing, the grain size also gets increased from e.g. 10 to 6 according to DIN EN ISO 463 / ASTM E112. The bigger the grain size, the smaller the statistical possibility for corrosion susceptibility. Besides the positive effects of solution annealing regarding corrosion resistance, this heat treatment makes our wire mesh products very deformable (ductile) as proven by excellent Erichsen Cupping Test results following ISO 8490 and ASTM E643-84.

A typical sand control panel contains about 8.7 miles of wires. Of course GKD only uses properly annealed wires for weaving process. But even if an annealed wire is used, it cannot be 100% inspected regarding existing chrome carbides. Chrome carbides are the reason for intergranular corrosion due to a decrease of chrome content inside the grain matrix. To ensure corrosion resistance, a chrome

content of minimum 12% is mandatory in every individual grain. The total surface area in a typical sand control panel is about 155 ft². Considering e.g. an average grain size of about 20 μm, there are about 46 billion grains available at the surface of the wires in each panel. Just one individual grain without enough chrome content can get the corrosion rolling.



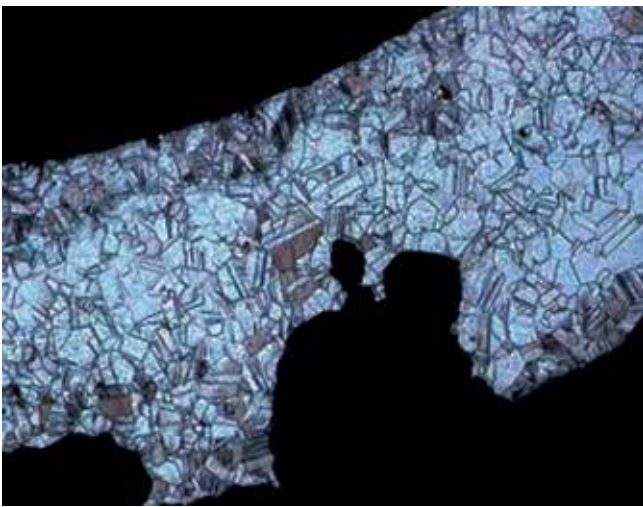
Grain structure of a heat-treated wire after weaving

Grain structure of a non heat-treated wire after weaving

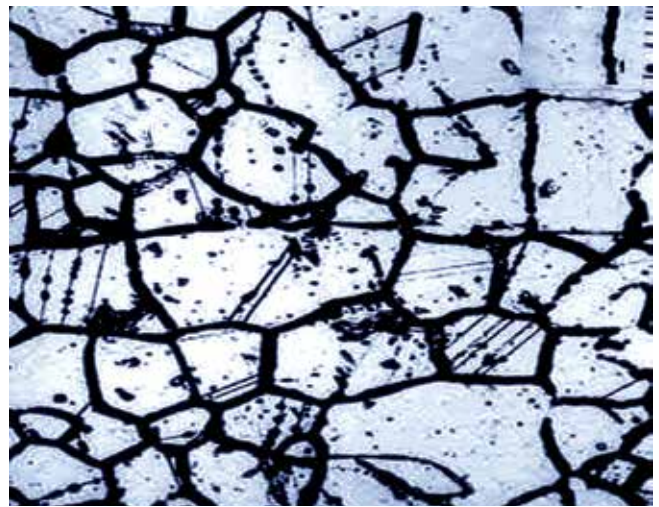
ANNEALING:

TYPES OF CORROSION

CORROSION PROPERTIES ACCORDING TO DIN EN ISO 8044



Pitting corrosion



Galvanic corrosion

IN OIL AND GAS APPLICATIONS THE MATERIALS USED ARE ALWAYS SUBJECTED TO CORROSIVE CONDITIONS OF VARYING SEVERITY.

In fact the dwindling reserves are forcing exploration in ever increasingly harsh environments which are acidic and/or contain high levels of chlorides. In addition to this, the combination of materials used and the high strengths which are required lead to a host of different forms of corrosion which have to be avoided. Some of the most common forms which are encountered include:

PITTING CORROSION

This form of corrosion occurs when the protective passive film of stainless steels is locally damaged, allowing the corrosive environment to come into contact with the unprotected surface of the metal. The passive film is capable of regenerating itself, provided that oxygen is present in the environ-

ment, but in the presence a high concentrations of chloride ions, it is possible that the rate of destruction of the passive film is faster than the regeneration and this then results in localized corrosion or pitting. Once pits have formed, they continue to grow at an ever increasing rate until in extreme cases the metal is perforated.

The resistance of an alloy to this is unfortunately common form of corrosion can be estimated empirically by using the so-called pitting resistance equivalent number (PREN) which is based on the chemical composition of the steel. Generally speaking, the higher number, the better the resistance to pitting. $PREN = 1 \times \%Cr + 3.3 \times \%Mo + 16 \times \%N$.

Further differentiation is given by a pitting potential of the Critical Pitting Temperature (CPT) which is determined by following the ASTM G61 and G150.

GALVANIC CORROSION

Galvanic corrosion is also called `dissimilar metal corrosion` and it is almost impossible to avoid this type of corrosion which arises due to potential differences when two dissimilar metals are placed in contact with one another in an electrolyte (corrosive environment). This essentially results in the formation of a battery in which one of the metals, the less noble, corrodes preferentially to protect the more noble metal. This form of corrosion can be reduced by ensuring that the potential difference between two contacted metals is as small as possible and by insulating the metals so that they are not in electrical contact with one another. ASTM G71 describes the procedure how to conduct and evaluate galvanic corrosion tests in electrolytes. This standard or guide also provides the selection of materials. Tests to determine the susceptibility of metals to this form of corrosion include visual examination after immersion in an electrolyte (typically 140,000 ppm chloride, 160°F, 14 days).

STRESS CORROSION CRACKING (SCC)

This form of corrosion arises when a susceptible material is

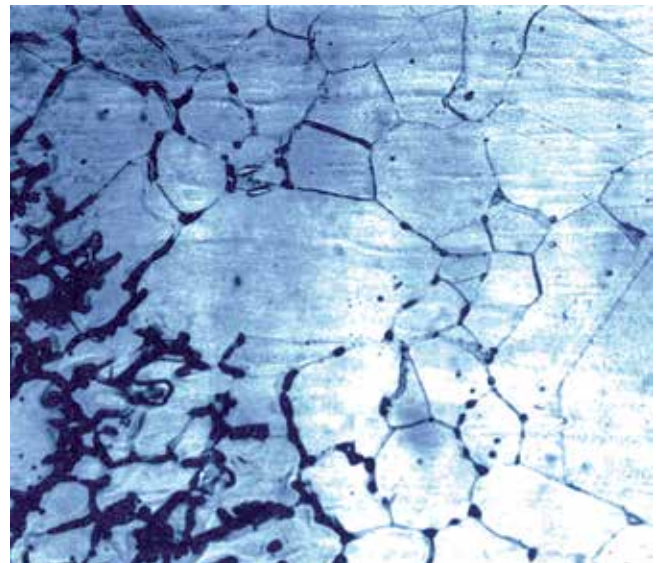
placed in a chloride or other halide containing environment and then subjected to tensile stresses. These stresses can either be residual or applied. The removal of any one of these conditions result in the avoidance of SCC. From this we can see that the residual and applied stresses must be kept as low as possible or that steps are taken to ensure that only compressive stresses are present. The latter requirement is the reason for the purposeful deformation of the inner surface of the hollow bars to produce high compressive residual stresses. High nickel contents are also known to promote stress cracking and it is for the reason that high grade non mags are not allowed with significant amounts of nickel. Susceptibility to SCC can be measured according to ASTM G36 and ASTM G123.

INTERGRANULAR CORROSION (IGC)

Although this form of corrosion is readily avoidable by accurate control of the chemical analysis and by performing adequate heat treatment, many customers require proof that the steels supplied are free from intergranular corrosion (IGC). The most common test to determine freedom from IGC are performed according to ASTM A262, Practice A and E.



Stress corrosion Cracking (SCC)

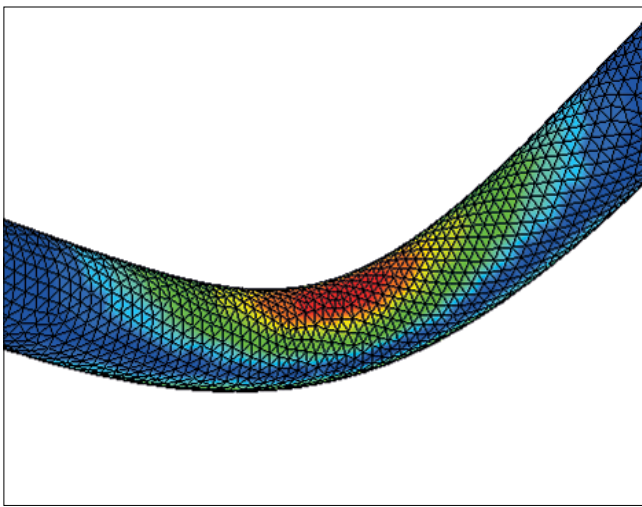


Intergranular corrosion (IGC)

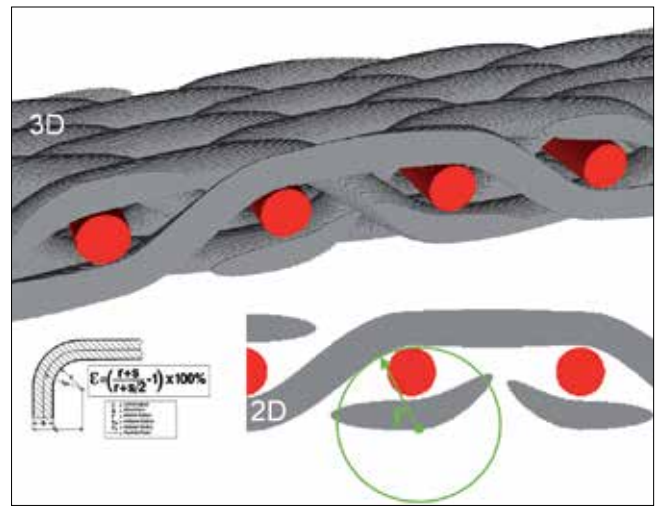
ANNEALING:

STATISTICS

SOME STATISTICS ABOUT THE EXISTING GRAIN STRUCTURE



FEM calculation showing local stresses of a deformed wire



Calculation of degree of cold work

CONCLUSION

- A solution-annealing of sand control screens increases the granular size (G10→G5/G6). Due to bigger, but much less grains inside an annealed sand control screen, statistically the possibility for an intergranular attack (corrosion) gets reduced.
- A weaving wire always slightly deviates regarding physical strength properties. Due to the additional cold forming process (“weaving”), local tensions inside a sand control panel vary as well, of course. By annealing, those additional tensions caused by the weaving process will be equalized.

WEAVING COMES ALONG WITH A COLD FORMING PROCESS

Depending on the chosen wire diameter and mesh construction called “weave pattern”, some wires get plastically deformed in a greater or lesser extent. It is an exemplary in-house

performed FEM calculation showing possible critical stresses of a deformed wire. Interesting to know is the fact that the highest stresses and of course highest tensions are located in the inner bending section due to the greater impact of compressing than elongation.

REASONS FOR ANNEALING AND FINISHING:

- Higher resistance to corrosion
 - Better formability
 - Increase of elongation
 - Improvement of pore size stability
 - NACE MR0175 compliant
 - Evidence for zero-defect sand control panels
 - Efficient, independent and documented outgoing inspection
-

3. FINISHING

AN INDEPENDENT INSPECTION PROVIDES CONFIDENCE



GKD's photometric inspection system

Considering that approximately 10 million pores are available inside a typical-sized sand screen, it is nearly impossible to visually inspect all pores and detect a deviation, even in case light inspection tables are used. Therefore we have installed in-house an independent optical control device that checks every sand screen leaving our facility.

WORKING PRINCIPLE

A line of LED high power light is mounted below an inspection table that has a slot that covers the complete width of a sand control panel. Above that slot, two high resolution inspection cameras are placed. The transmitted light method is used. Each panel is slowly pulled along the inspection table, so that 100% of all pores (in length and width) inside the sand control panels are checked for any irregularities (e.g. weaving faults that increase the opening). Besides purchasing the camera system, the camera inspection system had to be "trained". GKD

has collected many sand control mesh samples within the last twenty years while supplying the sand control industry. Our lab has analyzed those weaving faults to correlate what type of weaving fault generates whatever increase in opening. Based on that information, we can train and adjust the threshold level of the camera inspection system. Roughly speaking, the more light gets through the sand control panel, the bigger the opening but there are some specialties. Some weaving faults seem to be primarily huge, because a lot of light gets through an open pore, but the following glass bead test might show only a small increase in opening (e.g. + 5 μm). But it is also the case that some weaving faults appear to be visually small, but they actually produce an increase of pore size of about 150 μm or even more. That correlation between a visual irregularity detected by the camera inspection system and the measured increase in pore size opening is very important and the key to run a safe outgoing inspection.

DEVELOPING CUSTOMER SPECIFIC PRODUCTS

COMPUTATIONAL FLUID DYNAMICS (CFD) + FINITE ELEMENT METHODS (FEM)

When developing a filter media for sand control wells (Pipes) the task typically is to avoid particles in certain sizes to pass the mechanical filtration process. Woven meshes as the filter media have some advantages compared to other filter media e.g. they offer a high operational capacity at defined pore sizes, depending on the construction of the mesh called the 'weave pattern'.

Our in-house research and development activities at GKD focus on optimizing woven wire mesh geometries and the layout of the filter packages. Our woven wire meshes are continuously

analyzed to improve not just the permeability, but including other properties, e.g. mechanical stability. Finite Element Method (FEM) is used to localize critical weak points inside woven meshes or filter elements as well. Based on internal CFD-simulation recommendations for an effective sand retention are also provided.

In addition to selecting the correct filter media with a defined absolute opening, the layout of the different layers within the filter package must be selected with care. On the left side a filter package with a drainage mesh layer between the base pipe and the fine filtration mesh is shown. This design usually increases the flow rate in contrast to a filter package design without a drainage layer as shown in the right picture.



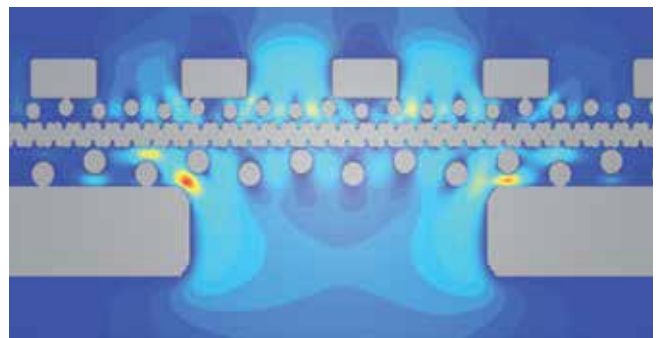
Filter package with a drainage layer



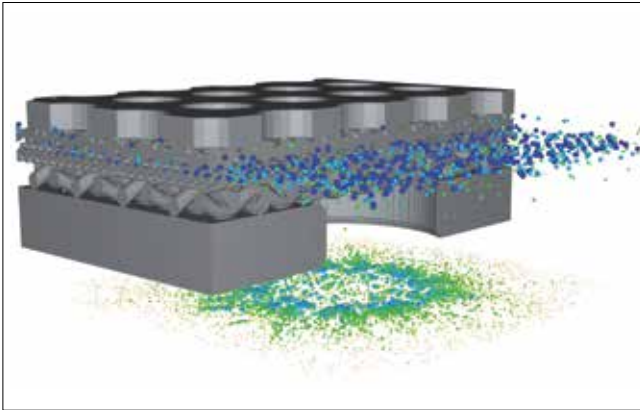
Filter package without a drainage layer



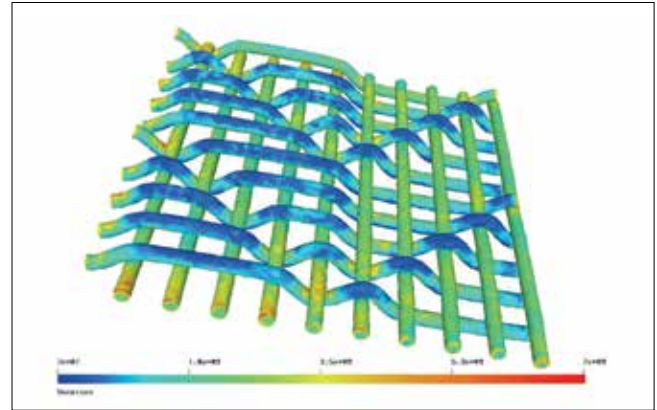
CFD simulation showing pressure drop



CFD simulation showing velocity



CFD flow simulation of a sand control application



FEM calculation of a wire mesh

Sieving and filtration meshes perform a variety of tasks in the field of oil filtration. GKD determines the ideal parameters for optimal mesh structures with the aid of in-house CFD simulations, among other things like FEM calculations. This is made possible thanks to the WeaveGeo[®] software tool used by GKD which utilizes the GeoDict[®] software suite for the mesh industry. GKD works in close collaboration with the customer to choose the types of meshes and patterns which are suitable for the specific application and determines their behavior under the relevant process conditions using complex mathematical algorithms.

To calculate the relevant mesh parameters the mesh pattern, the wire diameter of warp and weft, the warp and weft pitch, the crank factor as well as the rigidity and ovality of the wires can be altered virtually by means of CFD simulations. The computer simulations illustrate the mesh behavior as well as the flow and filtration properties. Parameters such as the maximum glass bead diameter, filtration efficiency, pressure drop at a specified media flow including filter cake, flow rate at a specified differential pressure as well as the bubble point can be visualized and previously hidden processes clearly followed as a result. On this basis a mesh or mesh package with optimum filtration properties in each case can be defined in no time at all. If necessary, a corresponding prototype can then be produced and tested in the lab.

GKD has succeeded in transferring this process to multilayer woven filtration mesh, too, with its WeaveGeo[®] software tool.

Multilayer meshes combine the benefits of various types of mesh in just one medium. Innovative mesh designs combine increased flexibility, mechanical stability, high throughput with lower differential pressure at the same time as well as absolute consistent pore distribution. A weave design stored in the WeaveGeo[®] software tool depicts the direction of the warp and weft wire. In addition to multilayer mesh even cables - together with the length of and direction of lay as well as the strands - can be designed and generated within a short period of time.

With the help of 3D simulations GKD is producing multilayer mesh - in eight different grades within the 60 to 600 μm range for a wide variety of applications - especially for the sand control business. For example, various combinations of RDTW meshes, Plain Dutch weaves, Dutch Twilled weaves and square meshes are being used as sand control screens in the field of offshore oil extraction. By filtering sand and solids they protect the oil pipelines against damage and prevent production outages. Depending on conditions on-site, various grades of mesh fineness are used which represents the best solution in terms of the required retention rate and the pressure loss caused by the filtration. To create a virtual model of the best project-specific mesh design with regard to the sand characteristics, information on the physical properties of the solids are fed into the program and evaluated. With the expansion of the worldwide exclusive feature of generating mesh by inputting data via weave cartridges, GKD is now able to create entirely new multilayer mesh patterns and designs.

GKD'S TYPICAL IN-HOUSE LABOR

EXTRACT OF MORE THAN 40 AVAILABLE LAB TESTINGS AT GKD



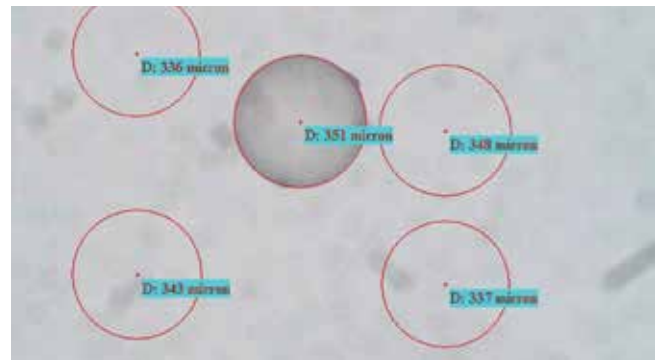
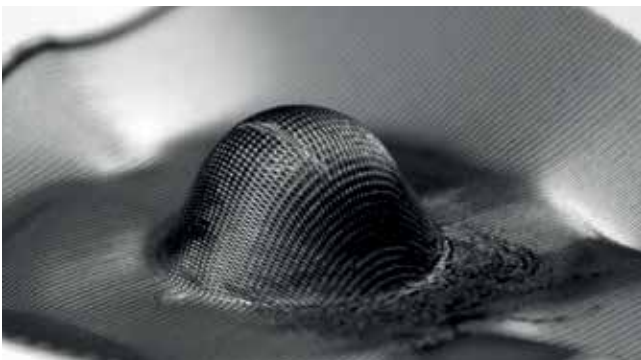
1. The chemical composition of our purchased weaving wires is checked according to ASTM A580 or DIN EN ISO 10088-3 by using our in-house X-Ray Fluorescence analyzers (XRF). If not the required extent of this incoming inspection of raw material (wires) is usually done according to DIN ISO 2859-1. The name of this standard is called "Sampling procedures for inspection by attributes - Part 1: Sampling schemes indexed by acceptance quality limit (AQL) for lot-by-lot inspection".

2. The physical properties of our purchased weaving wires for our woven wire meshes, like the tensile strength

and elongation are checked by default. GKD's tensile testing machines follow DIN EN ISO 6892-2. Its name is "Metallic materials – Tensile testing – Part 1: Method of test at room temperature (ISO 6892-1:2009); German version EN ISO 6892-1:2009".

3. Besides checking the air permeability, water permeability is even more important due to the use in aqueous phases. Our in-house water permeability device measures the throughput at various differential pressures. By knowing the thickness of the wire meshes, the Darcy values can be calculated as well.

LABORATORY TESTINGS



4. The name of this test is called "Metallic materials -- Sheet and strip -- Erichsen cupping test" and it follows ISO 20482. It specifies a standard test method for determining the ability of metallic sheets and strips having a thickness from 0,1 mm up to 2 mm and a width of 90 mm or greater to undergo plastic deformation in stretch forming.

5. The determination of the opening of a woven wire mesh is done according to ASTM D4751. The name of this standard is "Determining Apparent Opening Size of a Geotextile". This test identifies the biggest spherical particles that are able to pass the woven wire mesh. The identification of the biggest spherical particle that has passed

the filter media can be done manually or by using a particle counter like the Multisizer 4.

6. The air permeability of woven wire meshes is measured according to DIN EN ISO 9237. The name of this standard is "Textiles - Determination of the permeability of fabrics to air". Typical measurement results are provided in units like $l/m^2/s$ at a differential pressure of 200 Pa or CFM/ft^2 at 127 Pa.

7. Laboratory scale filtration testings are essential to predict important parameters such as the filtration efficiency, the cake-dependent pressure drop and the time-dependent permeability.



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GKD PROFILE

Weaving metal and other materials is the basis of our success. Since 1925, we have been continually re-interpreting the concepts of innovation and customer proximity. This passion for technology and exceptional solutions helped us to become one of the world's leading technical weaving mills within the fields of industry and architecture. With superior manufacturing technology and comprehensive process expertise, we constantly tap new fields of application. GKD meshes are used to develop efficient systems, complete installations along with individual components that are integrated into the processes for our customers in all sectors and industries. Our **SOLIDWEAVE** division regularly sets new standards in the development and manufacture of high-precision metallic meshes and complex technical filter systems. Countless innovations carry our name in the form of universal standard products as well as custom designs.

SOLIDWEAVE MANUFACTURING EXPERTISE

With pioneering weave technologies, developed in-house, we process both ultrafine wires and innovative material combinations. We make use of the very latest simulation technology in order to be able to optimally design the functionality of our mesh to suit the relevant process. Our comprehensive range of equipment, as well as our sophisticated machining and finishing processes guarantee the long-term reliability of our products, while also facilitating seamless integration into industrial production processes. These include thermal processes, automated strip cutting, winding and joining techniques, coating, calendaring, cleaning, as well as manufacturing under cleanroom conditions. Extensive inspection processes and strict, company-wide end-to-end quality systems allow for consistent product characteristics and comprehensible procedures. Customer satisfaction is always our benchmark.

GKD IS COMMITTED TO PROVIDING PRODUCTS AND SERVICE WHEREVER IT IS NEEDED, WORLD-WIDE.

- 01 GKD GERMANY, Düren (Headquarter)
- 02 GKD UK, Sherburn in Elmet
- 03 GKD FRANCE, La Roque d'Anthéron
- 04 GKD SPAIN, Barcelona
- 05 GKD USA, Cambridge, MD
- 06 GKD LATIN AMERICA, Santiago de Chile
- 07 GKD SOUTH AFRICA, Randfontein
- 08 GKD INDIA, Jaipur
- 09 GKD CHINA, Beijing
- 10 GKD MIDDLE EAST, Dubai
- 11 GKD MIDDLE EAST, Doha

