

Non-Metallic Composite Repair Systems for Pipes and Pipelines

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Traditionally mechanical defects in pipes and pipelines, which have been detected either by working on the pipeline or by intelligent pigging, have been repaired by replacing the defective areas with metallic pipe segments or by welding on metallic sleeves.

The use of thermosetting plastics and reinforcing fibres has a long and varied history of being used as a repair material for structural repairs.

The fabric options consist primarily of Carbon, Kevlar or Glassfibres, which are bound together and bonded to the pipe with various resin options.

Particularly the carbon fibres belong to the state of the art high-tech materials, which due to their outstanding tensile strength and very high stiffness are developing more and more new fields of application.

In modern aircraft construction (e.g. Airbus 380 and Boeing 787) carbon fibres are used in the construction of wings and tail fins to reduce weight while not compromising in strength.

In many of the car racing series the chassis are made of carbon, too.

In all areas where the combination of light-weight construction and high mechanical load capacity plays a dominant role, carbon fibres have established themselves as the material of choice (e.g. in such different business fields as the production of tennis rackets or communication satellites).

With the advent specialised resins and advanced reinforcing fibres, composites are now accepted in a wide variety of repair applications including piping systems and pipelines.

This technology has matured significantly in the last decade and is now widely used throughout the world by the largest and most technically advanced oil and gas companies.

Use of Composite or Laminate Repair Systems

Most of these systems can be broken down into two main categories of composite repairs:

- wet lay up-systems (in situ composites)
- pre-cured sleeve systems

Wet lay-up systems are impregnated or mixed in the field and cure in place on the pipe.

Besides epoxy there are a variety of polymeric matrix materials used in the field: such as vinylesters, polyesters and polyurethanes – all of which are classified as thermosetting resins.

Pipe repair composites generally have two main components, the reinforcing material and the adhesive resins.

The reinforcing material provides the strength and the adhesive resins provides the bond required to stay on the pipe and keep the composite's shape [1].

The first composite-or laminate systems-which were used for pipe repair have to be applied consecutively in several layers.

Due to the rigidity of this pre-impregnated composite systems, they could only be used on straight pipes, but couldn't be applied to non-straight geometries like bends, T-pieces or other irregularly shaped geometries.

These requirements lead to a diversity of solutions, from which the Black Diamond¹ composite system, which will be introduced in this article, plays an outstanding role based on its technical features and its ease of application.

Black Diamond System

Some 10 years ago Citadel Technologies, Tulsa, USA developed Black Diamond repair system to rehabilitate and to restore the original operational strength to corroded

¹ Black Diamond is manufactured by Citadel Technologies, USA, and distributed in Europe by DENSO GmbH.



Fig. 1: Repair of a gas-pipeline section in Turkey with Black Diamond system

Photo Courtesy of Citadel Technologies

pipeline systems. Black Diamond is named after a very rare and precious kind of diamonds.

The development got started by the idea to create a repair system for pipelines which could be applied fast and easily in case of detected defects or wall reductions on pipes.

Another practical point of view was to avoid welding in the application as due to the threat of an explosion, the use of it was not permitted in many areas.

After a successful restoring, the composite repair material should carry the mechanical loads together with the remaining pipe structure.

The result of these efforts is a 2-component composite system composed of two or three components.

The first component is a solid epoxy primer which issues complete bonding and load transfer between the repair and the metallic substrate.

The second component is a bi-directional woven carbon fibres material, which provides reinforcement in the hoop and axial directions.

It is the strongest available non-metallic repair material on the market.



Fig. 2: Application of Epoxy primer



Fig. 3: Wet out of carbon mesh with 2-component Epoxy wet-out

The third part of the binding force in the system is the polymeric epoxy “wet out” resin, which keeps the fibres in place around the pipe as well as seals the pipe and carbon fibre from the environment.

The Black Diamond system is wrapped in several layers around the pipe.

The number of layers is found by means of a special programme developed by Citadel Technologies called the Black Diamond Wizard®.

This application of the composite repair system should guarantee that during the repair work the line can remain in service without unscheduled shutdowns.

Thus tremendous costs of loss of production can be avoided.

This requirement was especially important in the field of refineries as each shutdown will generate expenses up to EUR 200.000 per hour!

On the contrary to glassfibre systems, carbon systems exhibits minimal creep and its stiffness approaches that of steel.

The Black Diamond composite system belongs to the group of wet lay-up systems. The curing time is dependent on the ambient temperatures, but will be approx. 5 to 6 hours if temperatures are near 24 °C (75 °F).

Due to the flexibility of the design referring to the specific conditions of each construction site, carbon composite systems can be used at nearly all conditions and sites- onshore and off-shore.

Limited excavation space and clearance highlights the use of Black Diamond system due to the simple installation procedure. This keeps the costs for civil engineering work on a delectable low level.

Carbon composites like Black Diamond can be installed on horizontal and vertical pipes with ease.

The application range of the composite material can stretch from +5 °C to +80 °C. High temperature application up to +160 °C are attainable with modified system components.

As carbon is electrically conductive, an electrical isolation by means of 2 to 4 layers of a 3-ply corrosion prevention tape e.g. DENSOLEN/BUTYLEN AS 40 Plus may be applied on top of the laminate system.



Fig. 4: Wrapping of saturated Carbon-mesh in several layers



Fig. 5: Rehabilitated Pipe Section prior to application of corrosion prevention system



Fig. 6: Electrical isolation and corrosion prevention by applying 4 layers of DENSOLEN Tape

This electrical isolation is notably important if the pipeline is protected by a cathodic protection system to avoid any interference or loss of voltage.

Four layers will be reached by two wrapping processes with 50 % overlap each.

The Black Diamond system complies with American DOT specs, ASME PCC-2 art 4.1 and 4.2 and the new ISO Standard ISO TS 24817 “Composite repair material for pipelines”.

DENSO GmbH is in close co-operation to reputable operators and testing institutes in Europe to set down the ground rules for approvals and further testing parameters thus providing for all customers the highest possible security level for composite repair systems.

The basic fundamental issues for evaluating composite repair methods are as follows

- mechanical strength of the composite material
- environmental effects (e.g. cathodic disbondment, temperature, acids and alkalics)
- effects of pressure (Both static and cyclic. Bursting and fatigue tests should give information to these issues.)
- mechanics of load transfer from pipe to wraps
- long term performance issues
- consistency of application and quality control in manufacturing

In the a.m. guidelines, ASME PCC 2 and ISO TS 24817 equations are listed for the evaluation and calculation of composite repair methods and based on the criteria pipe specifications and defect validation [2].

Meanwhile a lot of test has been carried out especially for the Black Diamond system. The currently missing link of all composite systems are long term test data (especially in terms of the adhesive resins) [3].

In 2007 a diversified and in depth long-term test set up for composite repair materials was launched in the USA. This testing is designed for a period of 10 years and each year an evaluation of all participating systems will be executed.

In Germany the base for calculations, equations and testing set-ups will be approved and accompanied by the Quality Service Company TÜV.

Since 2006, the first practical tests and applications were executed by some major operators, which has been accompanied and supervised by TÜV organisations. These applications have received excellent feedback from all parties involved.

The basis for the evaluation of these repair systems is the new draft of VdTÜV guideline “Guidelines for the qualification of repair methods for pipelines – performance test/procedure test” [4].

This guideline describes the procedure for the qualification of repair methods suited for the repair of defects on pipelines.



Fig. 7: Ready-for-use repair kits for 36" pipe (DN 900)

Photos 2-6 Courtesy of RAKW Wiidau.

Due to the diversity of the repair systems, only general information and requirements are listed in the guideline.

The guideline regards itself as an introduction to this complex topic to restore defective pipelines to their original integrity by the use of composite repairs.

By means of the described methods pipe defects can be repaired permanently or temporarily depending upon the pipe specifications and defect characterizations.

Application of Black Diamond System

Before the repair work will start, the current status of the pipe system will be validated and documented.

The number of necessary wraps or layers will be evaluated with the assistance of a calculation software or calculation table and confirmed by the operator and the third party quality supervisor.

The evaluation of the composite repair method is based on the remaining wall thickness of the pipe, the state of the coating surface, the maximum operating temperature, the pressure of the pipe and the characteristics of the changing pressure.

With this information input the calculation programme (Black Diamond Wizard®) analyses the information to determine the number of wraps required for each pipeline repair.

Before starting the repair work, the operator and authorised third party expert must confirm their approval to the execution in written form.

The subsequent application of the repair will be executed exclusively by trained and certified personnel of companies which have to prove their ability according to DVGW Guideline GW 301, G 1 "Gas pipelines for all pressures and diameters", as well as complete the specified training course of the composite system manufacturer.

All materials specified in an engineering assessment come to the jobsite pre-cut to length and packed in cartons, which ensures that all necessary material to complete the job are packed into the kits already.

The defective area of the pipe section has to be prepared according to cleanliness SA 2 ½ to provide a high adhesive shear strength.

At heavily corroded areas that require a prior modification of the areas (e.g. heavy pitting), a high modulus putty filler should be applied to smoothen the surface for an appropriate application of the epoxy primer.

The filler putty ensures that proper load transfer takes place between the host pipe and the composite repair, as well as reduces stress concentrations in the defect area.

After the application of the epoxy primer, the carbon fabric will be saturated with an epoxy wet out and applied in several layers/wraps according to the engineering assessment (4-6 layers = 2-3 mm total thickness) around the pipe.

The transition from the repaired pipe section to the factory coating shouldn't be executed with the Black Diamond system. During the application of the Black Diamond system, the factory coating will not be involved in this process. As soon as the epoxy adhesive is cured – dependent from ambient temperature – between 5–6 hours after application – a corrosion prevention system according to EN 12068 class C 50° will be applied and the factory coating will be incorporated in the coating in a width of 10 cm on each side. In case of an above ground construction, an aluminium tape with a butyl adhesive will be wrapped on top of the carbon repair system and encapsulate the entire repair area stretching from the original coating on one

side to the original coating on the opposite side.

Complex geometries like bends, T-pieces, reducer pipes can be repaired with the Black Diamond system as well due to the flexibility of the carbon fabric.

Current Prospects of Using Composite Repair Systems

A survey of the US Department of Transportation pointed out that by using composite repair methods, the overall costs can be reduced by 24 % compared to welding on pipe sleeves. Compared to the replacement of the defective pipe segments completely approximately 73 % of all costs can be saved.

The US Department of Transportation which is in charge of the regulatory framework for the operation and construction of pipelines in the USA, issued the following Government Regulation in January 2000.

According to this document, the requirements for repairing corroded areas and dents in pipelines are as follows:

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“The pipe transportation system must be repaired by a method – that as reliable engineering tests and analyses show – can permanently restore the service availability of the pipe” [5].

This passage made its way into the new US guideline ASME PCC 2 art 4.1. and 4.2 in 2006 (Post Construction Code: Repair using non-metallic materials) [6].

In nearly identical wording of this PCC 2 guideline these requirements were transferred into the newly established ISO Standard TS 24817 (Composite Repair of pipeworks) [7].

Conclusion

By use of these composite technologies it is possible to repair defective areas on pipelines originated by corrosion, abrasion, or mechanical damage.

A full restoration of the pipeline can be successfully executed even up to a loss of 80 % of the original wall thickness. During the repair work the line can remain in service. There is no shutdown of the pipeline necessary for the benefit of the wrap application.

The application of the system will be executed by trained and certified personnel only, who can document their ability by an installer certificate issued through Citadel Technologies or by Citadel authorised organisations.

The supervising personnel of the operator, who are in charge of the operational service of the line and as well the quality authorities of the Third Inspection Party may be trained and certified in theory and practical application by the manufacturer as well,

in order that they can properly identify the difference in a correct and incorrect composite repair.

Due to these new measures, the criteria “Safety“ and “Quality“ of the maintenance and repair of pipelines will be given absolute top priority.

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