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DEVELOPMENT OF LARGE-DIAMETER CONTINUOUS-FIBER-REINFORCED THERMOPLASTIC PIPE

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SHORT SUMMARY
This article discusses the development of the technique in producing large-diameter, medium-and-low-pressure water-delivery pipes. The continuous fiber-reinforced thermoplastic tapes perfectly-impregnated with thermoplastic resin are wound layer by layer to form three-layer fibre reinforced polyethylene(PE) composite pipe (CGFR-PE) with inner and outer polyethylene layers as the protective functional layer and the middle continuous fiber glass belt as the reinforcing layer. There are stiffening rib designed in the outer layer to be used for bell-and-spigot joint.

KEYWORDS
Continuous glass fiber belt; impregnate; wind; bell-and-spigot joint

ABSTRACT
The large-diameter (>1000mm) medium and low-pressure (0.4-1.6Mpa) water delivery pipe market is very attractive for plastic pipes. Compared with the traditional thermoplastic solid-wall pipe, the continuous glass fibre reinforced polyethylene(PE) composite pipe (CGFR-PE) has its significant advantages of technical and economic indicators below: Stable and reliable performance, environmental protection and energy saving, high pressure bearing capacity, convenient and reliable socket connection, low production cost and the like, which has a good market prospect in this field. This text introduces the structural design, strength calculation, connection technology, production technology and equipment of the glass fibre reinforced PE pipe, etc. The specially-designed multi-station winding device and the socket online finishing device are all our patented technology-friendly products. This will also help greatly improve the production efficiency, and ensure the overall consistent performance of the pipe wall and make the socket connection more reliable. For the reason that it is very difficult to detect the pressure-resistant properties of large-diameter composite pipes by exerting hydrostatic tests. Therefore, this text mainly discusses how to test the 'initial apparent radial strength' and the 'initial apparent axial strength' by means of the 'Split Disc Method' (ASTM D 2290), instead of the traditional hydrostatic test (ISO 4427). This text also explores a test scheme for detecting the long-term reliability of composite pipe by means of the Split Disc Method.

INTRODUCTION
Rongyee Engineering Pipeline Corporation, a Chinese high-technology enterprise in the pipeline production industry, developed the technique of producing large-diameter, medium-and-low-pressure, water-delivery pipes by melting and winding reinforcing layers. This article includes the description of the production process and some of the discussions on the test and producing procedures.

NOMENCLATURE
Continuous glass-fiber-reinforce thermoplastic Polyethylene pipe; Stiffening-rib; Blasting-pressure; Ring-stiffness; Ring-softness.

EXPERIMENTAL

Hydrostatic test (nominal pressure; test pressure; test temperature; test time); Blasting test (nominal pressure; blasting pressure; safety factor); Split disc method (initial apparent axial strength)

DISCUSSION

I. It is a historic opportunity for us to explore and develop the large-diameter continuous fiber-reinforced thermoplastic pipe.

The plastic pipe coming out in the last century has played an important role in the history of human development and progress. In the global and Chinese pipeline markets, the thermoplastic pipe meeting the requirements of health, environment protection and sustainable development has shown its competitive advantages in the application of small and medium-diameter pipes, and is gradually expanding its market share. However, in the application of medium and large-diameter pipes, the traditional pipe is currently mainly adopted, e.g. concrete pipe, cast iron pipe, glass steel pipe, etc. As the human society pays more and more attention to health, environment protection and sustainable development, with the innovation and progress of technology, the thermoplastic pipe has faced a historic opportunity to enter the medium and large-diameter pipe application field and open up a broader market.

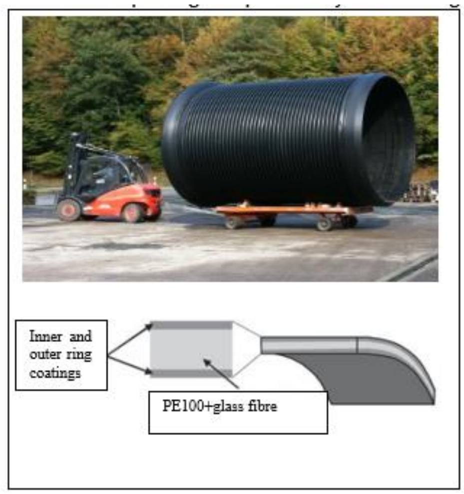
In the past, during the evaluation of a pipe product, the economic cost was the main consideration under conditions that the basic application requirements could be met. When selecting the pipes, no priority would be generally given to health, environment protection, sustainable development and other factors. For example, in the past, it was possible to accept the easily-corroded metal pipe and any anti-corrosion measures that might affect the environment; to ignore the consumption of a large amount of energy caused by the heavy weight of pipe during production, transportation and laying; and to tolerate the waste that could not be recycled after use. However, the future development trend in the world will give priority to the requirements of health, environmental protection and sustainable development. The traditional pipe products that cannot meet the requirements will shrink sooner or later and even be eliminated (in which the current cost advantages of some traditional pipe products will inevitably be lost in the future). The thermoplastic pipe with its outstanding advantages in health, environmental protection and sustainable development will inevitably enter the application field of medium and large-diameter pipes gradually.

Till now, the limitations of the properties of thermoplastics and the backwardness of the pipeline manufacturing process are the main obstacles to hinder the thermoplastic pipe from entering the medium and large-diameter pipe field. It is well known that, as the strength and stiffness of thermoplastics are relatively low, it is difficult for the full thermoplastic pipe to meet the performance requirements for the medium and large-diameter pipe applications. For example, although China has also been able to manufacture the HDPE solid-wall pipe with a diameter of 2m, this kind of pipe can only be applied to low-pressure water transmission because of the limitations of plastic properties. Although the thermosetting plastics and fiberglass composite FRP pipe has been widely used in the medium and large-diameter pipe field, with the increasing demand for environment protection and sustainable development, the FRP pipe industry is facing an urgent situation of product upgrading. The thermoplastic and high-strength fiber composite pipe is still relatively backward. The reason is that, for years, there is no international solution to the technically difficult problem for the perfect and full composition of high-strength fibers (glass fiber, carbon fiber) and thermoplastics (the fibers shall be properly impregnated with the resin), and the reinforced effect of high-strength fiber on the plastic pipe cannot be fully played. Since the beginning of the new century, there have already been breakthroughs and promotions concerning the technology of high-strength fiber perfectly-impregnated with

thermoplastic resin. At present, China has also been able to massively produce the Continuous Fiber Reinforced Thermoplastic Tape by means of the melt impregnating process, which has been successfully applied to the automobile, aviation and other fields, and which is gradually being promoted to the field of plastic pipes. Although the application in the plastic pipe field is currently, temporarily, and mainly limited to the medium and small-diameter high-pressure pipe field, the exploration of applying the continuous glass fiber (carbon fiber) reinforcement technology to the medium and large-diameter plastic pipe field has already started and is in progress. We are facing a new opportunity for technological innovation and development.
So far, no company in the world has published the information on the successful development of the continuous-fiber-reinforced medium-and low-pressure medium-and-large-diameter thermoplastic pipe. We have published the results of exploratory experiment, in order to communicate with international counterparts, jointly develop the new products with great market prospects, and meet together a historic opportunity for the new development of the plastic pipe products.

II. Development of the layer-by-layer winding process of the continuous fiber reinforced polyethylene pipe

The target market for the continuous-fiber-reinforced medium-and low-pressure large-diameter thermoplastic pipe is the range of diameter of 800-2000mm and working pressure of 0.4-1.6 MPa. Its difficulty is that the strength of thermoplastics is not high. Currently, for the most widely used HDPE100, its MRS value is only up to 10 MPa; its design strength is only up to 8 MPa. For the pipe SDR17, its pipe diameter is up to 1000 mm; its working pressure is up to PN1.0 MPa; its wall thickness is close to 60 mm. Not only are the material consumption and the cost of the pipe staggering, but also the requirements for extrusion molding process and technical equipment are very high. During the laying construction, on-site welding is required and it is very difficult to transport and operate the larger machines & tools. Therefore, the promotion and application of large-diameter thermoplastic pipe are limited, and it is necessary to develop a new type of large-diameter plastic pipe.



For years, the German KRAH Company has been exploring the possibility for forming the large-diameter plastic pipe and fabricating the three-layer (polyethylene inner liner + glass fiber reinforced layer + polyethylene outer protective layer) structural large-diameter composite pipe by the winding welding process. The glass fibre reinforced polyethylene pipe (called the PE-GF pipe) developed by this company has not only entered the international market, but also has already started trial production in China.
The PE-GF pipe is provided with the three-layer structure, including: Inner & outer layers of PE100 and intermediate layer of short glass-fiber-reinforced PE100. The wall thickness of the PE-GF pipe is thinner than that of the polyethylene solid wall pipe. The PE-GF pipe shall be connected by means of the butt fusion welding or electric fusion welding and other processes. In recent years, this kind of pipe has not only been widely applied in Belgium, Turkey, Colombia, Japan and other regions, but also has already reached the DIN and ASTM standards (**DIN SPEC 19674, ASTM F2720**). It can be seen that its reliability has been affirmed. The DN4000 1MPa SN8 PE-GF pipe manufactured for Australia shall be shown in the right figure.
The PE-GF pipe developed, has made great contribution to showing that the thermoplastic plastic pressure pipe shall not necessarily be manufactured by means of the traditional direct extrusion

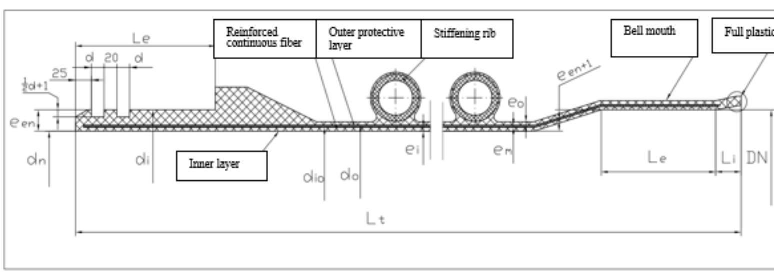
method, but possibly by means of the multilayer winding welding method. This has created a new process for the development of large-diameter plastic pressure pipe. However, the PE-GF pipe developed, has not been widely accepted. According to the company's report (2013), there are only 9 production lines for manufacturing the PE-GF pipe in the world. According to the analysis, the reason is that, the short glass-fiber filling reinforcing material of PE100 has been used in the intermediate reinforcement layer, so that the reinforcing effect is not obvious: The MRS value of the highest grade of material PE-GF 200 is only up to 20 MPa, and its design stress is up to 12.5 MPa (**DIN SPEC 19674** [1]), which is only 1.56 times higher than the design stress of PE100 (8 MPa). Therefore, there is no significant role in improving the carrying capacity of the pipe, reducing the material consumption and lowering the cost. In the competition with the conventional pipes, e.g. ductile iron pipe, welded steel pipe, pre-stressed steel cylinder concrete pipe (PCCP), glass fiber reinforced plastic mortar pipe (RPMP) and the like, this kind of pipe has no distinctly unique advantages, unless it is necessary to apply the non-excavation laying technology.

Therefore, the main target is to search for a reinforcing material with its higher reinforcing effect.

After years of research and development, our company has selected the high-strength Continuous Fiber Reinforced Thermoplastic Tape as the reinforcing material, and has successfully developed the "polyethylene (PE) large-diameter continuous fiber reinforced composite pipe" (hereinafter referred to as the "continuous fiber reinforced composite pipe") by means of multi-layer winding welding forming process.

1. Structural design of the "continuous fiber reinforced composite pipe":

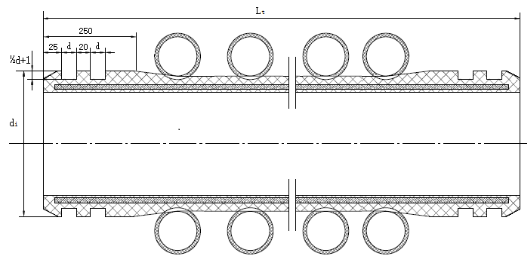
The “continuous fiber reinforced composite pipe” is also a three-layer winding forming technological design: Polyethylene inner liner + Continuous Fiber Reinforced Thermoplastic Tape reinforced layer + polyethylene outer protective layer (Fig. 1). By calculation of the bearing capacity of the pipe, it can be set that all the loads will be carried by the glass fiber tape. The inner and outer polyethylene layers are only the protective functional layers. Considering that it needs to be buried as a water transmission pressure pipe in most cases, it must make sure that there should be sufficient ring stiffness of the pipe. Therefore, after reinforcement by using the high-strength fiber glass tape, the wall thickness of the pipe can be significantly reduced. However, in order not to affect the ring stiffness of the pipe, a stiffening rib shall be provided outside the polyethylene outer protective layer. According to the needs, the stiffening ribs with different specifications can be wound to achieve the required ring stiffness of the pipe.



2. Connection of the “continuous fiber reinforced composite pipe”:

Because of its larger diameter, the "continuous fiber reinforced composite pipe" cannot be wound at a large angle to achieve the purpose of balancing the radial and axial reinforcement of the pipe, but shall be wound at a winding angle of approximately 90^0. Therefore, the maximum reinforcement will be obtained in the radial direction of the pipe, so as to greatly improve the bearing capacity of the pipe. However, the reinforcement will not be obtained in the axial direction of the pipe, so that the pipe cannot axially withstand the axial force arising from the internal pressure. So only the socket connection can be used. Since the glass fiber tape has a relatively high elastic modulus, the practice has shown that, only if there are enough winding layers, we can fabricate the bell mouth and socket that can meet the socket connection requirements. Through a series of piping system operation simulation tests, it is proved that it is feasible and reliable for the "continuous fiber reinforced composite pipe" to adopt the socket connection.

In order to improve the production efficiency of the winding pipe, and avoid causing easily any quality problems by directly making the bell mouth on the pipe, according to the improved design, the connecting sleeve shall be fabricated as follows: Both ends of the pipe shall be made into the sockets, while the two ends of the other pipe shall be separately made into the bell mouths (Fig. 2). The connecting sleeve can be processed and manufactured in a variety of ways; because of its shorter length, the connecting sleeve has its better rigidity, to facilitate the socket connection; meanwhile, also make it easier to carry out the necessary mechanical cutting and reprocessing of the bell mouth; and make sure that the bell mouth has its sufficient geometric accuracy and form & position tolerances.



Schematic diagram of the pipe

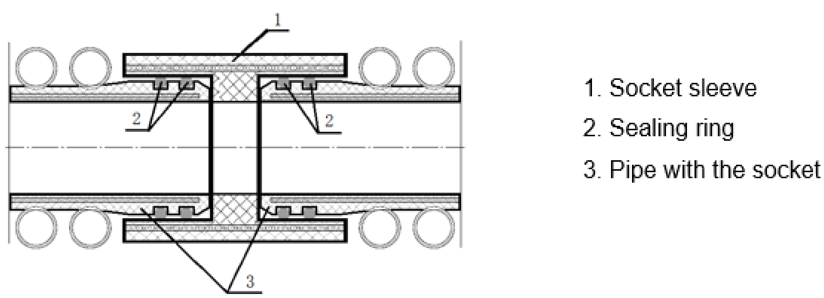


Fig. 2

III. Selection of the reinforced material:

The development and application of the reinforced pipe in China have existed for many years. The reinforced pipe is attempted to be made of all types of reinforced materials. At present, the “steel wire mesh skeleton reinforced polyethylene (PE) composite plastic pipe” has been more successfully and more widely applied. Its structural characteristics: The two-layer or multi-layer winding forming steel wire mesh reinforcing layer is set between the inner and the outer pipe walls (Fig. 3).

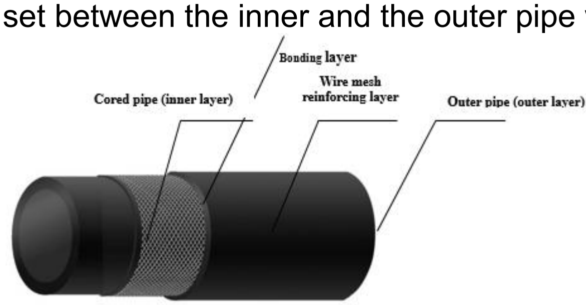


Fig. 3

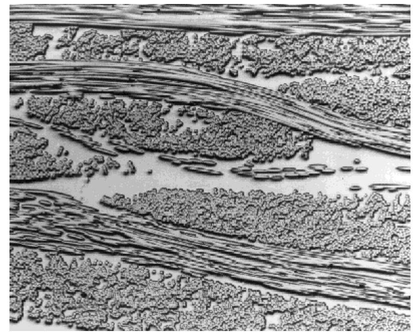
The “steel wire mesh skeleton reinforced PE composite plastic pipe” can not only adopt the high-strength (2000 MPa) galvanized or copper-plated steel wire as the reinforced material, but also can bond the inner and outer layers of the steel wire mesh and the polyethylene pipe into a whole by using the hot-melt adhesive, so as to achieve the significant reinforcing effect. However, due to the existence of steel wire, the pipe can only be connected with the electrofusion welded fittings or flanges. Due to the limitations on the production of large-diameter electrofusion welded fittings, the pipe diameter will be subject to certain restrictions. Currently, the maximum diameter of the pipe is up to 630- 800mm.

The "continuous fiber reinforced composite pipe" will select the Continuous Fiber Reinforced Thermoplastic Tape as a reinforcing material. The glass fiber has not only its advantages of low price and high strength, but also has its disadvantage of being easy to break and relatively brittle. Since the international breakthrough in the technical difficulties of impregnating the high-strength fibers with the thermoplastic plastics and overcoming the shortcomings of easy brittle fracture of glass fibers, there has emerged a new trend in the development of thermoplastics and fiber composite material. First of all, such composite material has been widely applied in the automotive, aerospace, military and other fields, and then there has also immediately emerged an upsurge in the innovative development of the high-strength fiber (glass fiber, carbon fiber) reinforced thermoplastic pipe in the plastic pipe field, called the "continuous fiber reinforced thermoplastic pipe" **CFRTP-Continuous Fiber Reinforced Thermoplastic Pipe**, recently also internationally known as the "thermoplastic plastic composite pipe" **TCP-Thermoplastic Composite Pipe**.

In China, there are already many companies that can produce the basic material for **CFRTP - "Continuous Fiber Reinforced Thermoplastic Tape**" **CFRTT** in batches. Its performance is close to the international advanced levelThe exploratory development of **CFRTP/TCP** is also very enthusiastic and very quick to start in the pipeline industry of China. Through independent exploration & development and international cooperation, there are relatively mature process and equipment technologies for the small-diameter high-pressure **CFRTP/TCP** in China. The "Jilin Rongyee Engineering Pipeline Co., Ltd." has not only developed the process and equipment technologies (section winding methods) for the large-diameter medium and low-pressure **CFRTP/TCP**, but also has made delectable achievements.

In accordance with the most important requirement for the basic material for **CFRTP –** CFRTT (**Continuous Fiber Reinforced Thermoplastic Tape)**, the glass fiber must be carded neatly, evenly distributed and fully impregnated with the resin. Through the practices of long-term production and application, it has been internationally recognized that, only after its being well-impregnated and coated with the resin, the glass fiber can be safely and reliably given full play to its advantages, and avoid its inherent defects.

Despite its very high strength, the glass fiber is a brittle material. The surface of the glass fiber filament is rough and uneven, so it is not resistant to wearing, folding and twisting. If it is not impregnated and coated with the resin, the glass fiber filament will be easily damaged and broken. Moreover, because of its relatively large surface area and non-resistance to chemical medium corrosion & water erosion, the glass fiber filament is also required to be impregnated and coated with the resin.

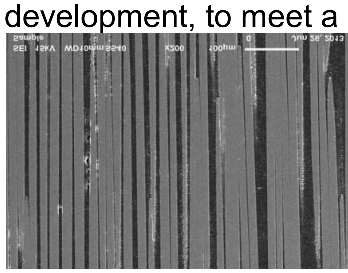


The ideal combination is that the surface of the glass fiber filament can completely be impregnated and coated with the resin.

After the glass fiber filament is perfectly impregnated and coated with the resin, there will be a relatively large interface (relative to the diameter of the glass fiber filament). Therefore, when subjected to load and deformation, the glass fiber filament and the resin can uniformly withstand and react (to avoid stress concentration).

If the glass fiber filament not perfectly impregnated with the resin has been used to reinforce the pipe, the reinforcing effect can also be seen in the short term. However, during the production, transportation, laying and use, the glass fiber may be moved and deformed due to various reasons. The glass fiber filament not impregnated and coated with the resin may be damaged due to the friction, folding or twisting between the fiber filaments, so as to significantly reduce the ability to withstand the load and ultimately lead to an accident. Because it is difficult to predict and control any changes in external conditions, the glass fiber filament not perfectly impregnated with the resin cannot be used to reinforce the pipe. The electron microscope image of the "Continuous Fiber Reinforced Thermoplastic Tape" (**CFRTT)** made in China shall be shown in the photo below. It can be seen that the glass fibers are arranged neatly and evenly.

If the glass fiber filament perfectly impregnated with the resin has been used to reinforce the polyethylene pipe, the significant effect will be achieved. Under conditions of the same diameter and the same pressure level, compared with the polyethylene solid wall pipe, the wall thickness can be reduced by about 30%, the materials can be saved by 20%, and the production cost of the pipe can be significantly reduced. Due to its light weight, convenient transportation & construction and energy-saving, compared with the traditional pipe, it has its significant advantages in terms of hygiene, environmental protection and sustainable development, to meet a promising market prospect.



Electron microscope image of **CFRTT**

The technical index requirements for **CFRTT** shall be shown in Table 3:

Table 3: Mechanical Properties, Dimensions and Permissible Deviations of the Glass Fiber Reinforced Tape

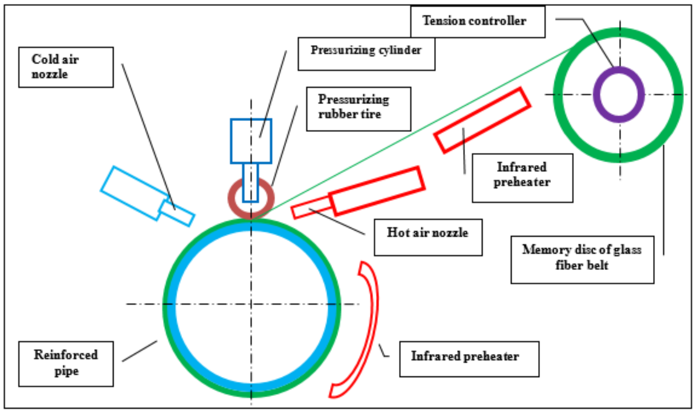
Item	Index	Allowable deviation
Width (mm)	50	±1.0
Thickness (mm)	0.3	±0.03
Tensile strength (MPa)	＞600	
Tensile elongation (%)	＜5	
Glass fiber content (%)	＞60	


The compositing process of the fiber layer

IV. Characteristics of process and equipment

Main steps of reinforced pipe production are: extrusion and filament winding of polyethylene inner layer, filament winding of reinforced layer of continuous glass fiber belt, extrusion and filament winding of polyethylene outer layer as well as filament winding of PP stiffened rib pipe coated with polyethylene.
Key points are:
1. The steel mould shall be preheated to about 160-180 C °.
2. The polyethylene inner layer shall be subject to multi-layer winding namely at least two layers. The rear layer shall be pressed on the front layer (overlaid layer by layer).
3. After the polyethylene inner layer is cooled to 60℃, under the rotation and movement of mould, the continuous glass fiber belt shall be heated with certain pressure given while it shall be wound on the basic layer in turn so as to realize winding, welding and compositing of reinforced layer of continuous glass fiber.
4. The polyethylene outer layer is also subject to multi-layer winding.
5. The auxiliary extruder shall extrude PP stiffened rib pipe coated with polyethylene and wind so as to realize composite welding of stiffened rib pipe.
6. The rough pipe casting and steel mould shall be moved to the cooling station for cooling and demoulding.
Production device with “double noses and three stations” under PLC automatic control shall be adopted to improve the production efficiency and realize all the processes above. Details are as follow:
1. The first station shall produce inner layer of reinforced pipe. The mould shall be preheated, upon completion of many times of winding and then transferred to the second station. The second mould shall be put into the first station to carry out production of the second basic layer pipe.
2. The second station. Under the cooling action of strong cold air, cool to below 60ºC and then the inner pipe is formed. Winding and compositing of continuous glass fiber belt shall be conducted. The warm air machine shall act on the heating area of wound position and apply certain pressure on glass fiber belt during the process of winding and compositing. Weld quality between inner pipe and glass fiber belt shall be ensured to form a complete solid wall.
3. The third station. Upon completion of compositing of reinforced layer, the pipe shall be moved to the third station to wind and form the outer layer. At this time, production of the second basic layer pipe on the first station has been completed thus it shall be moved to the second station to wait for cooling and forming, and then compositing the continuous glass fiber belt. Then the third mould shall be put on the first station to process the basic layer pipe.
4. On condition that three stations operate simultaneously, the equipment shall maximize the efficiency. So the production line shall include three stations and five moulds.

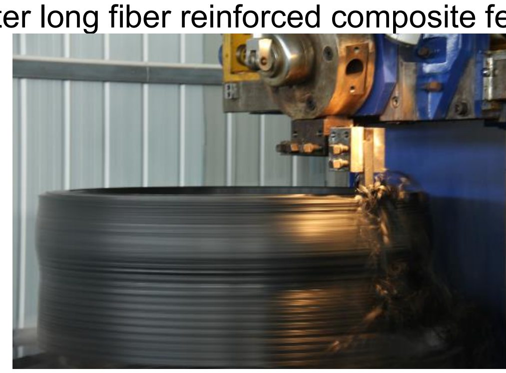
5. The off-line pipe shall be subject to demoulding by mould dismounting machine, finished by finishing machine, processed by socket sealing rubber ring groove and then subject to hydrostatic test of 20 minute (s) by 1.5 times the working pressure. Finally the qualified “continuous fiber reinforced composite pipe” shall be completed.



Sketch map of compositing process of reinforced layer of continuous glass fiber belt

Production device of double noses and three stations

Heating device of the first station of production line of PE large-diameter long fiber reinforced composite feed/drain pipe



Processing device of pipe end

The connecting sleeve is processed by dedicated processing device

V. Long-term strength of “continuous fiber reinforced composite pipe”:

Target market of “continuous fiber reinforced composite pipe” is medium and large-diameter water delivery pipeline while this market has a high demand for pipeline reliability because accidental pipeline burst may result in serious consequences and heavy losses. Therefore, long-term bearing capacity of pipe must be subject to test so that the test results shall serve as basis for determining grade of product bearing capacity. The difficulty of the problem lies in that the performance of composite pipe cannot be calculated in accordance with long-term bearing capacity of raw materials as it can be done for ordinary plastic pipe material. The reason is that raw material of pipeline is composite material and the ratio of reinforced material and plastics of pipeline of different specifications and grades varies greatly. Therefore, pipe can be subject to “assessment” only through direct test.

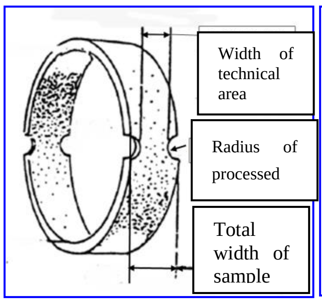
Internationally, long-term bearing capacity assessment of reinforced thermoplastic pipe is usually conducted based on ‘**API RP 15S Qualification of Spoolable Reinforced Plastic Line Pipe** [1]’ which is equally applied as ‘**SY-T 6794-2010 assessment of Spoolable reinforced plastic pipe**’[2] by our national Petroleum Standards. At present, China uses ‘**5** assessment procedure’ of this standard for reference to assess the long-term bearing capacity of composite pipe. The specific method is to divide the product into ‘product category’ according to diameter and the ratio of reinforced material and plastics and then select pipeline of one of the specifications as ‘representative of product category’. According to stipulations of **ISO/DIS 9080-1999 (GB/T 18252-2000)**, a series of hydrostatic stress rupture test are performed to obtain the regression failure curve of long-term hydrostatic strength of product category and lower confidence limit (**LCL**) which shall serve as the basis of assessment of long-term bearing capacity of pipeline of this product category. This assessment procedure is internationally recognized. However, for large-caliber “continuous fiber reinforced composite pipe”, this method shall waste time and energy with no general representative significance. Furthermore, the obtained value cannot serve as basis of bearing capacity assessment of pipeline of other product category.

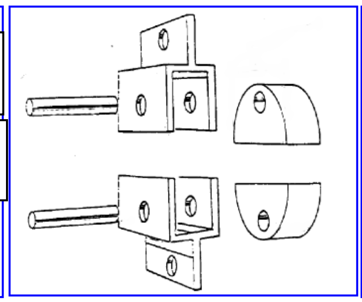
Test shall be conducted under condition of set test temperature and constant pressure while the test requires at least **18** failure points. At most **2** points with failure time within **100h**, at least **3** points with failure time between **1000h~6000h** and at least **1** point with failure time exceeding **10000h**. Finally, according to the test data, average regression curve of long-term hydrostatic strength (**LTHS**) and lower confidence limit **LCL** of product category shall be determined.

For “continuous fiber reinforced composite pipe” with larger diameter, this method is difficult to carry out. Hydraulic test for greater number of large-diameter pipe (dozens of samples) with higher pressure (several MPa) and longer time (maximum over **10,000** hour) requires large and expensive test equipment and tools with high cost. However, the results obtained can only assess ‘one product category’ of glass fiber reinforced pipe product thus the results have no general representative significance. Therefore, complete implementation of **API RP 15S** method is theory-based but is not feasible in practice. Even if any enterprise performs it at any cost, it cannot be used to guide the pressure rating of the pipe produced. So we tried to make regression analysis on test data acquired through a series of stress rupture tests under constant stress loading condition and then we obtained the average regression curve and method of lower confidence limit **LCL**; we selected “Split Disc Method” (**Split Disc Method**).

The “**Split Disc Method**” shall judge bearing capacity of composite pipe through measuring hoop tensile strength of pipe. Principle of “Split Disc Method” is very simple. The sample is a narrow ring cut off from the vertical axis of the pipe while the test tool is a metal plate divided into two halves (separating disc). Outer diameter of the disc slide fits the inner diameter of the sample ring while the thickness is slightly larger than that of sample ring. The test shall be carried out on general tensile test machine. Hoop tensile load shall be formed inside the sample ring through connecting the clamp. The load F which can snap the sample ring shall be measured and divided by the area **S** of the broken section of plastic pipe sample so as to obtain the **apparent hoop tensile strength** of sample. From this apparent strength and size data of the pipe, a safety factor shall be considered to calculate the pressure-resistant property of pipe. Results of a large number of practices at home and abroad prove that the results obtained via Split Disc Method are consistent with that obtained from hydraulic test.

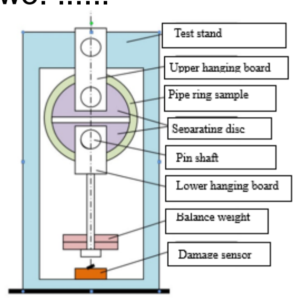
Internationally, common standard of Split Disc Method is American '**ASTM D 2290:12 Standard Test Method for Apparent Hoop Tensile Strength of Plastic or Reinforced Plastic Pipe'** as method standard of measurement of apparent hoop strength of plastic pipe or reinforced plastic pipe **[2]**. This standard was first published in **1964** while the current version was released in **2012**. "Split Disc Method" has already been applied to thermoplastic pipe and reinforced thermosetting-plastic pipe. For example, the industrial standard established by our country in 2016 '**High performance unplasticized poly (vinyl chloride) pipes and fittings for water supply'** requires to measure 'apparent hoop tensile strength' and stipulates to execute the test method in accordance with **ASTM D 2290**. Glass reinforced plastic pipe industry in China also applies this test method in its quality management system. For example, the standard '**GB-T 21238-2007 glass fiber reinforced plastics mortar pipes'** stipulates that delivery inspection shall include 'initial hoop tensile strength' instead of 'hydrostatic strength' test.






Therefore, it is of great significance to discuss the feasibility of using "Split Disc Method" instead of 'hydraulic test' for long-term bearing capacity assessment of large-caliber "continuous fiber reinforced composite pipe".

We noticed that the same exploration is being done abroad since the limitation of merely using "hydraulic test" fails to adapt to development of large-diameter composite pipes: The famous magazine PIPE & PROFILE EXTRUSION released an information about the 'creep test' on 18th page of the journal of January to February 2016[3]: "Japanese researchers have developed a method of ring tensile creep test of composite pipe, although stress rupture test is the main test method to test the long-term durability of composite pipe, the researchers from Osaka Natural Gas Company and Kyoto Technical Institute of Toyobo express that an easier and more convenient test method is needed. The ring sample shall be subject to test rather than the whole pipe. Through comparison of test results of the two types, there is a good correlation between the two. ...... "



Sketch map of tensile test stand of pipe ring test

1. The scheme of measuring long-term bearing capacity of glass fiber reinforced pipe with "Split Disc Method"

The new scheme to test the long-term bearing capacity of large-caliber "continuous fiber reinforced composite pipe" follows the internationally recognized API RP 15S standard to assess long-term bearing capacity of pipe. Method of stress rupture test is changed from 'hydraulic test' to "Split Disc Method".

The new scheme shall greatly reduce the test expenses, save the expensive test equipment and shorten the test time. Furthermore, it offers a simple and practical method to control the product quality of routine production.

2. Short-term hydrostatic test (including blasting test) shall not serve as method of daily (delivery inspection) judgment of short-term property against internal pressure of pipe while only the blasting test is reserved.

Short-term compressive strength of thermoplastic plastic solid-wall pipe is usually judged by short-term hydrostatic tests. Generally, **2-3** different test conditions (temperature, pressure or stress, time) shall be stipulated. In our country, short-term compressive strength of reinforced thermoplastic pipe with small diameter and high pressure is also measured with blasting test.

It is difficult to conduct hydrostatic test for large-diameter **CFRTP** and even more difficult to conduct blasting test (especially when it is required to conduct test under bell and spigot joint but the pipe shall be kept from the axial force generated by internal pressure in the axial direction). If hydrostatic test included in delivery inspection requires frequent implementation, the production enterprises can hardly achieve it. Thus experience of sand sandwiched fiber glass pipe can be referenced namely and short-term hydrostatic test shall not serve as method of judging the pipes' short-term property against internal pressure.

Consequently:

--- In **CFRTP** product standard, the medium and short term hydrostatic shall only retain the blasting test and the hydraulic test with **1.5** times working pressure which shall be performed when each pipe comes off the production line. The time shall be shortened to a few to 10 minutes to test the stability of production process. This item shall be included in the factory inspection.

--- Safety factor of the blasting test shall take **3** to serve as the short-term bearing capacity of the pipeline (in accordance with the experience of measuring short-term compressive strength with blasting test for reinforced thermoplastic pipe with small diameter and high pressure.)

--- The blasting test shall be included in the type test and the method of blasting test shall be stipulated, which factory inspection no longer requires.

In the standard **GB/T 21238** of sand sandwiched fiber glass pipe, the stipulated safety factor $\mathbf{C_1}$ is very high: 'when there is no **HDP** result of long-term hydrostatic design pressure benchmark test, $\mathbf{C_1}$ is equal to **6.3**'. We know that is because of the complex structure and material of sand sandwiched fiber glass pipe, and the manufacturing process is difficult to control strictly while thermoset plastics is featured by distinct brittleness. Therefore we take such a high safety factor. The basic material of "continuous fiber reinforced composite pipe" is uniform and stable polyethylene. Reinforced material is polyethylene glass fiber reinforced belt in which glass fiber is completely impregnated by resin. The pipe shall be subject to multi-layer winding and compositing and then the three-layer structure shall be welded into a whole. Various kinds of domestic product standard of reinforced thermoplastic pipe require that the blasting pressure shall be more than 3 times the working pressure which is equivalent to the safety factor 3. Consequently, we believe that it is reasonable and appropriate to take 3 as safety factor of "continuous fiber reinforced composite pipe".

3. Inspection of short-term compressive strength — the initial hoop tensile strength shall be measured by tensile pipe wall hoop sample instead of short-term hydrostatic test

Standard **GB/T 21238** of sand sandwiched fiber glass pipe shall be referenced to measure the 'initial hoop tensile strength' which is actually an apparent strength. Pipe wall of composite structure is measured as homogeneous solid-wall pipe. **Short-term compressive strength** of pipe shall be determined with 'initial hoop tensile strength' **as item of delivery inspection**. The test is simple namely the sample is cut off from pipe wall along the hoop while the sample may be a pipe ring with a width of **20mm** or dumb-bell shape tensile sample cut off along the hoop.

--- Initial hoop tensile strength shall be measured through stretching pipe wall hoop sample

--- Then calculate with following formula $\mathbf{E_{th}=C_1 \cdot PN \cdot DN/2}$ to judge whether the working pressure is safe.

--- $\mathbf{C_1}$ is stipulated to be **3**. When the diameter, working pressure and $\mathbf{C_1}$ are confirmed, $\mathbf{E_{th}}$ can be calculated while calculated value table of $\mathbf{E_{th}}$ shall be listed in product standard. The measured initial hoop tensile strength shall be larger than calculated value of $\mathbf{E_{th}}$.

--- Listed in items of delivery inspection.

Method of measuring ‘hoop tensile strength’ is similar to that of measuring “apparent hoop strength” of pipe based on standard **ASTM D 2290-12** ‘method standard of measuring apparent hoop strength of plastic pipe or reinforced plastic pipe (namely ‘Split Disc Method’). The difference between the ‘hoop tensile strength’ and ‘apparent hoop tensile strength’ obtained from the test shall be divided by the wall thickness.

4. Measure the initial axial tensile strength through stretching pipe wall axial sample

‘Initial axial tensile strength $\mathbf{E_{tl}}$’ is also an apparent strength, which is also measured by the pipe wall of composite structure as homogeneous solid wall. The test is also simple while the sample is cut off from pipe wall along the axial direction.

GB/T 21238 stipulates there are two calculating methods of $\mathbf{E_{tl}}$ which differ greatly:

Method one: ‘when the pipe **does not bear** the axial force directly generated by internal pressure of pipe, or when it is not subjected to special axial force, the initial axial tensile strength $\mathbf{E_{tl}}$ of pipe wall shall be no less than the specified value in Table **6**.’

Method two: ‘when the pipe **bears** the axial force directly generated by internal pressure of pipe, the initial axial tensile strength $\mathbf{E_{tl}}$ of pipe wall shall meet the requirement of formula (**2**). Following formula shall be used to calculate:

$\mathbf{E_{tl}=C_1 \cdot PN \cdot DN/4}$, to judge whether the working pressure is safe.

Requirements of the two methods differ greatly.

Design of “continuous fiber reinforced composite pipe” CFRTP uses glass fiber belt to reinforce in hoop while completely not reinforce in axial direction. CFRTP does not bear the axial force directly generated by internal pressure of pipe. Therefore, **CFRTP** adopts bell and spigot joint of rubber ring seal. Thus it is enough to meet the condition of “one of the methods”.

Although **CFRTP** adopts bell and spigot joint of rubber ring seal and does not bear the axial force directly generated by internal pressure of pipe, pipe shall bear the axial load which may be generated during laying (such as hoisting) and operation (such as differential settlement of pipe base). Currently, **we have no basis on how to estimate the required axial strength. Therefore, one of the $\mathbf{E_{tl}}$ methods stipulated by GB/T 21238 can be used to meet the specified value of Table 6.** The reason is that **GB/T 21238** is tested by practice and can prove that when bell and spigot joint of rubber ring seal is adopted, the pipe does not bear the axial force directly generated by internal pressure of pipe. The ‘initial axial tensile strength $\mathbf{E_{tl}}$’ greater than specified value of Table **6** ensure the axial safety of pipeline.

Consequently:

--- The initial axial tensile strength shall be measured through stretching pipe wall axial sample

--- In accordance with stipulations of Table 6 of GB/T 21238, $\mathbf{E_{tl}}$ value shall be included into the standards so that the users can check and enterprises shall be prevented from reducing wall thickness blindly.

--- Listed in test of delivery inspection.

VI. Operate simulation test:
Because of **the crucial importance of "continuous fiber reinforced composite pipe" CFRTP application, users tend to query the long-term safety performance including the long-term reliability of bell-and-spigot joint. As pipeline development and manufacturing enterprise, we are also concerned about these problems so we designed an operating simulation test facility: based on 1.5 times the nominal pressure of pipeline, continuously run a group of pipeline and combined system of pipe fitting with a number of socket joints for thousands of hours in order to verify the design calculation, manufacturing process and installation reliability of the pipeline. This test has been conducted for 2400 hour (s).**

CONCLUSIONS

We developed the technique of producing 3-layer continuous glass fiber-reinforced thermoplastic pipe on the basis of long practice and took many advanced theoretical studies as references. Although there should be more to improve and a long way to go, it is definitely a main trend in this area. Thanks to many frontiers' study and we would like also contribute to the development of this area and welcome anyone who would like to discuss and exchange ideas with us.

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REFERENCES

1. Exploration in developing large-diameter reinforced plastic pressure pipe; Yuchuan Zhang, Nian Wu. Oct. 2015.
2. ASTM D 2290:12 Standard Test Method for Apparent Hoop Tensile Strength of Plastic or Reinforced Plastic Pipe.
3. There should be great risks in applying thermoplastic pipe reinforced by glass fiber filament not impregnated. Yuchuan Zhang, April, 2017.
4. New scheme of testing the long-term carrying capacity of continuous fiber reinforced polyethylene pipe. Yuchuan Zhang. January, 2018.
5. Standard GB/T 21238-2016 of sand sandwiched fiber glas.