IMPROVING THE WATER INGRESS PERFORMANCE OF SUBMARINE CABLES

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Abstract: When submarine cables are damaged by external forces, it is possible for sea water to enter the cable structure aided by hydrostatic pressure. During marine repairs, the removal of 'wet' cable can be a slow and costly operation. Therefore, cables designed and manufactured with good control over the axial water blocking characteristics are very important for the future maintenance. This paper investigates improvements in the water blocking characteristics of submarine cables investigating the performance of fibre gel, water blocking compounds and process controls used in the manufacture of Light Weight (LW) Cable. Extensive hydrostatic tests and sea trials have been performed on LW and armoured cables. Results are presented which show the relative water blocking performance improvements and conclusions are made which can be useful in the future designs of submarine cable.

Key words: Submarine cable, water ingress performance, fibre gel, water blocking compounds, process control

1. INTRODUCTION

Since the invention of submarine cables, they have performed a critical role in global communications, especially with the explosive growth of the internet and capacity demand on international communications. However, submarine cables can be exposed to the risk of damage by earthquake/tsunami, fishing and exploitation of marine resources. When submarine cables are damaged by external forces, it is possible for sea water to enter the cable structure aided by hydrostatic pressure and incur a huge communications and economic loss. During marine repairs, the removal of wet cable and universal jointing of new cable can be a slow and costly operation. How to improve the water ingress performance of submarine cables is very important for the future maintenance.

Hengtong Marine Cable Systems (HMCS) a professional manufacturer of submarine cables has carried out some research about the water ingress performance of submarine cable.

2. CABLE DESIGN

All the R&D reported here are based on the HORC-1 light weight cable designed by Hengtong Marine Cable Systems. The cable meets the industry standard ocean deployment depth of 8000m which covers most transoceanic cable routes. The structure of HORC-1 LW is shown in Figure 1.

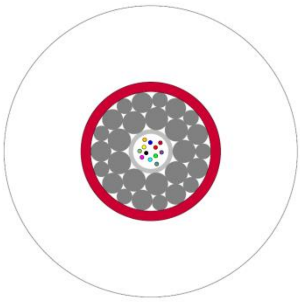

Figure 1: Cable Structure of HORC-1 LW

Because of the special application environment, a good water ingress performance is very important to ensure a relatively short water ingress length when cable damaged. For the special submarine cable structure, the central Fibre In Metal Tube (FIMT) and the gap of inner armour wires are most susceptible to water ingress. The improvement of the water ingress performance of FIMT and inner armour gap are the key design activities reported here.

3. WATER INGRESS EXPERIMENT MODE

In order to quantify the water ingress limitation along the submarine cable when damaged by external forces on the seabed and prove that the maximum water ingress length is compliant with the design specification a practical measurement was undertaken. The experiment was designed as shown in Figure 2.

Figure 2: Water ingress experiment mode

Test method as follows:

1. Both ends of the cable are in the pressure vessel, one end is sealed and the other end is exposed to the water pressure.

2. The cable sample is placed inside the large pressure enclosure which is then filled with water and pressurized.

3. The cable sample is removed after a number of days and inspected internally along its length for signs of water.

4. Fluorescent dye is added to the water in the pressure vessel, for inspection by ultra violet (UV) light after testing.

In the experiment mode, acceptance criteria has been evaluated using Formula 1.

$$L=K*(P*T)^{0.5} \quad \text{Formula 1}$$

Constant K is selected 5 usually.

Where, P is pressure in (MPa), T is time in (days) and L is the length of cable affected by water ingress (m).

4. WATER BLOCKING MATERIALS SELECTION

For submarine optical cable, the key cable elements requiring water blocking are the FIMT and Inner armouring structure. It is important to select the suitable water blocking materials, which are practical for use in production and retain their properties throughout the 25 years design life of the cable.

4.1 Fibre Jelly

In the submarine cable design, a special fibre jelly is selected as a protective, hydrogen absorbing and water blocking material for use in the FIMT. It is very important to evaluate the main material performance and good processability of the jelly because it contacts the fibres directly. After a series of comparison and verification tests, HMCS chose a suitable fibre jelly ID: Jelly-1.

4.1.1 Viscosity

Viscosity of fibre jelly has a big influence on tube processability and water blocking performance. Too high a viscosity will adversely affect the tube filling, and too low a viscosity will adversely affect the water blocking performance. So a moderate viscosity range from 6000-10000mPa.s@20℃ is a good selection. This viscosity range achieves a good balance between low tension fibre extraction for jointing while also controling the fibre movement within the cable structure during deployment and recovery operations.

4.1.2 Hydrogen Absorption

Hydrogen is known to produce a loss increase in optical fibres. The loss increase is caused by two additive phenomena, including degradation of GeO_2, which is irreversible and interstitial penetration in the silica core, which is reversible. Hydrogen traces that might be found inside the cable structure can originate from 3 sources: (a) released by the cable raw materials, (b) electrolytic cells formed inside the cable structure and (c) hydrogen produced outside the cable core and permeating through the cable materials.

So in order to avoid the adverse influence of hydrogen, fibre jelly should have good hydrogen absorption ability.

4.1.3 Material Stability

In order to satisfy a 25 year design life, fibre jelly should have a good material stability, including color stability, water resistance, non-reactive, non-corrosive and non-degrading when in contact with fibre coatings, copper, aluminium and steels. The material should be safe for handling and storage, having a long shelf life. Jelly-1 is ideally suited for use in stainless steel tube constructions and will not degrade and remain stable for 25 years cable design life.

4.1.4 Service Temperature

First, the storage and operational temperatures of submarine cables range from -30 to +60°C,

Second, fibre jelly was preheated to higher than 100°C to inject into the tube during the tubing production,

Third, the LW cables were quickly cooled in several seconds during HDPE extrusion, so the fibre jelly inside will be lower than 80°C.

The last, other possible conditions including copper patch repair were been considered. Temperature of fibre jelly is been evaluated lower than 120°C.

So the service temperature of fibre jelly should cover the conditions. Jelly-1 is recommended for use over the service temperature range -40°C to +120°C. It can satisfy cable requirement.

4.1.5 Health & Safety

All cable materials are sourced with a Material Safety Data Sheet, and recommended safety precautions are strictly followed.

4.2 Water Blocking Glue

In the submarine cable design, there are gaps between the steel wire which can allow sea water ingress. This water ingress phenomenon increases under higher water pressures. Therefore it is necessary to apply water blocking materials into the steel wire gaps and prevent the penetration of sea water.

Two types of water blocking materials are commonly used in cable manufacture, one is water-swelling type and another is a sealed-filling type. Because of the special application environment, high water pressure, the sea water will ingress before water-swelling material has time to activate, resulting in the water penetration along long lengths of submarine cable. In contrast, sealed-filling material can prevent sea water ingress into the structure effectively.

It's very important to evaluate the main material performance and good processability of water blocking glue, including viscosity, mixing ratio & gel time, high and low temperature performance, hydrolytic stability, dry heat aging, hydrogen generation, corrosion resistance and fungus resistance.

HMCS has cooperated with Material suppliers and developed a two-component water blocking glue: COMPOUND-A/B after comprehensive research.

4.2.1 Viscosity

During the inner armour process, a suitable viscosity is very important for processing. A balance has to be found, with low viscosity only a little glue will remain on the surface of steel wires, but higher viscosity materials increase the processing difficulty. A experimental approach showed that the viscosity of two compound mixture is optimum at 500m.Pas@25°C.

The viscosity of COMPOUND-A/B is tested as Table 1.

Sample Name	Test Method and Condition	Value Unit :cP	Average Unit :cP.
Part A	ASTM D2393 Viscosity, Brookfield-RVT,@25℃	582	582
		587	
		579	
Part B		290	287
		286	
		287	
Mixed A+B		514	514
		517	
		511	

Table 1: Viscosity of COMPOUND-A/B

4.2.2 Mixing Ratio & Gelling Time

In order to ensure the inner armour processability and operation time, it is necessary to define a suitable gelling time. Too short gel time will cause problems upon re-start after the line has been stopped for wire changes and joining operations, and will create material waste.

Thinking about the processability and line operations a gel time in the region of 14 to 24 hours @25℃ was considered suitable. The COMPOUND-A/B, mixing ratio of A and B compound was fixed at 100 to 30 in weight and this was used to determine the properties discussed below.

The gel time of COMPOUND-A/B is tested according to ASTM D2471 as Figure 3.

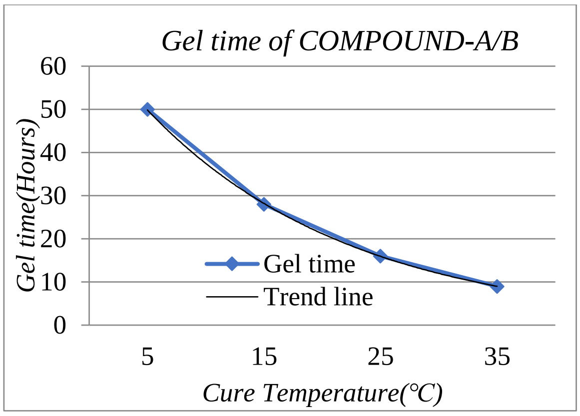

Figure 3: Gel time of COMPOUND-A/B

The glue sample after cure is shown in Figure 4.

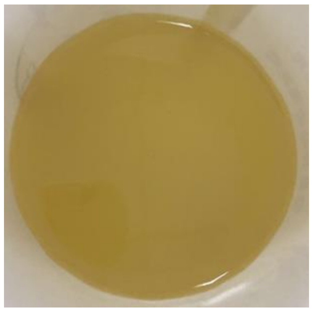

Figure 4: COMPOUND-A/B after cure

4.2.3 High-and-low Temperature Performance

For submarine cable, the storage temperature can range from -30 to+60℃.Therefore it is necessary to evaluate the mechanical properties over this range -30 to +60C.

Cured glue was put in the test condition for 2 hours and then removed to test the hardness and toughness.
Test results are shown in Table 2.

Sample Name: COMPOUND-A/B	
Test Temperature	Hardness (Shore D)
-40℃	2.4
-10℃	2.7
25℃	2.6
70℃	2.7

Table 2: Hardness in different temperature

The tests confirmed that after the extremes of temperatures, properties of COMPOUND-A/B at room temperature were not changed.

4.2.4 Hydrolytic stability &Dry heat aging

A good hydrolytic stability can avoid generating possible moisture which may influence inner armour wires and copper conductor. Dry heat aging performance is important to quantify as this can influence on the cable design life of 25 years.

To check the water absorption and hydrolytic stability, cured sample weight change was determined after soaking in boiling water for

168hours. Results are shown in Table 3 and Figure 4.

Sample Name: COMPOUND-A/B			
Weight before aging (g)	Weight after aging (g)	Rate of change %	Average %
3.192	3.216	0.75	0.63
4.736	4.761	0.53	
3.751	3.774	0.61	

Table 3: Hydrolytic stability of COMPOUND-A/B

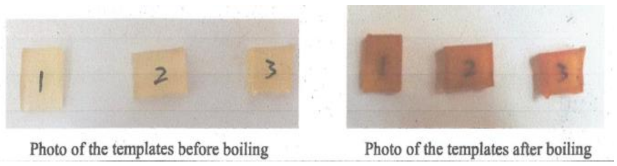

Figure 4: Photos of templates before and after boiling

To check the thermal aging & material stability, cured sample weight loss was determined after dry heat aging for 500hours at 100°C. The results are shown in Table 4 and Figure 5.

Sample Name: COMPOUND-A/B			
Weight before aging Unit: g	Weight after aging Unit: g	Rate of change %	Average %
4.290	4.195	-2.21	-2.29%
4.577	4.462	-2.51	
4.095	4.007	-2.15	

Table 4: Dry heat aging of COMPOUND-A/B

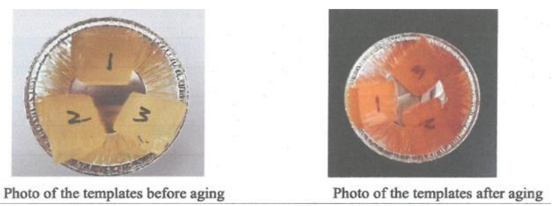

Figure 5: Photos of templates before and after aging

Test results showed that, COMPOUND-A/B has a low water absorption and aging weight change. All the samples have a good dimensional stability and a little shrinkage after the critical test

4.2.5 Hydrogen generation & Corrosion resistance

It is necessary to check the hydrogen generation of the water blocking glue and corrosion reactivity with steel wire and copper.

Samples of steel wires and copper tapes were mixed in COMPOUND-A/B, and well packed in sealed bag for set time to detect any hydrogen generation. Experiment steps are shown in Figure 6.

Figure 6: Experiment steps of Hydrogen generation & Corrosion resistance

Test results were shown in Table 5.

Sample Name: COMPOUND-A/B				
Sample Weight	Volume of Bag	Test Condition	Test Item	Test Data
130g	3L	GB/T 13610-2014	Hydrogen concentration,%	0.012

Table 5: Hydrogen generation & Corrosion resistance of COMPOUND-A/B

The Hydrogen generation (Hg) should be:

$$Hg=\left(V-\left(\frac{M}{\rho}\right)\right)*(Hc1-Hc2)\Big/M. \qquad \text{Formula 2}$$

Where:

Hg: Hydrogen generation.
V: Volume of bag.
M: Weight of glue.
ρ: Density of glue.
Hc1: Hydrogen concentration.
Hc2: Hydrogen concentration in the air (0.005%).

$$Hg=\left(3-\left(\frac{0.130}{0.96}\right)\right)*(0.012\%-0.005\%)\Big/130=1.54\mu l/g.$$

Results showed that hydrogen concentration (0.007%) is very close to the concentration in the air (0.005%). It's very low concentration

Because the fibre jelly has a good hydrogen absorption ability of more than 200µl/g, so the hydrogen concentration of COMPOUND-A/B can be accepted.

4.2.6 Fungus Resistance

Water blocking glue has a gel time of 16 to 24 hours, and it is necessary to ensure the gel performance is not affected by fungal contamination during operations.

Main fungus performance evaluation was shown in Table 6.

Test Fungi	Test method	Concentration of spores (Spores/ml)	Rating observed growth on specimens (After 28 days)
Aspergillus brasiliensis[A] ATCC 9642	ASTM G 21-15	$1.0*10^6$	0 Grade
Penicillium funiculosum[B] ATCC 11797			
Aureobasidium pillulans ATCC 15233			
Chaetomium globosum ATCC 6205			
Trichoderma virens[C] ATCC 9645			

Table 6: Fungus resistance of COMPOUND-A/B

Where:

0-None;

1-Trace of growth(Less than 10%);

2-Light growth(10 to 30%);

3-Medium growth(30-60%);

4-Heavy growth(60% to complete coverage).

Test results showed that COMPOUND-A/B satisfy the requirement of fungus resistance.

4.3 Health & Safety

All cable materials are sourced with a Material Safety Data Sheet, and recommended safety precautions are strictly followed.

4.4 Raw materials influence on joint.

Fibre jelly and water blocking glue do not change any cable jointing procedures or joint performance

5. TECHNICAL IMPROVEMENT OF WATER INGRESS PERFORMANCE

In order to achieve a good water ingress performance, some technical improvements were researched.

5.1 Improving the water ingress performance of FIMT

For submarine cables, FIMT is selected as key element to protect fibres and shown in Figure 6.

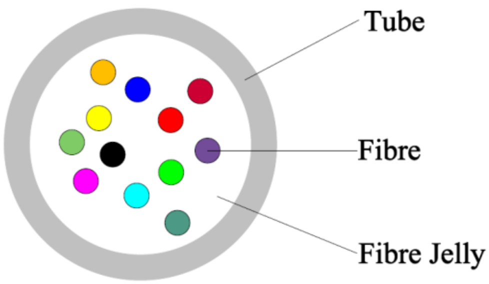

Figure 6: Structure of FIMT

To guarantee a good water ingress performance, fibre jelly fill into the tube during tubing process. The filling rate of fibre jelly(Fr) is the key control factor and can be expressed by the following Formula 3.

$$Fr=\frac{M*100\%}{L\rho 1(\frac{\pi}{4}D^2-\frac{\pi}{4}nd^2)}$$ Formula 3

Where: M-Fibre jelly weight, L-Tube manufacturing length, ρ1-density of fibre jelly, D-inner diameter of tube, d-outer diameter of fibre, n-fibre counts.

Five FIMT samples were manufactured with different fibre jelly filling rate to check the influence on water ingress performance. All these filling rates all achieved with 4 fibres. The water ingress test condition was 14 days at 20Mpa water pressure.

Test results were shown in Figure 7.

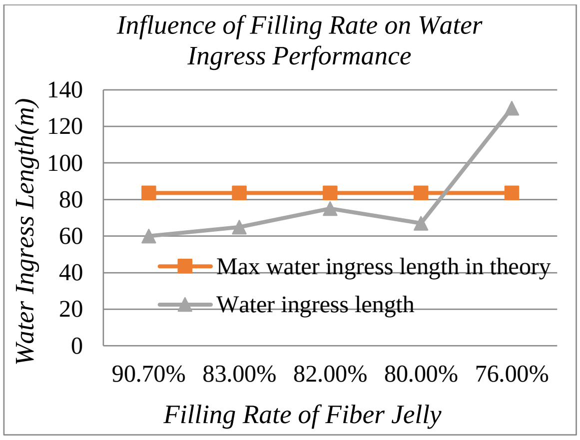

Figure 7: Influence of filling rate of fibre jelly on water ingress performance

Test results showed that water ingress performance of FIMT will be improved with the increase of filling rate of fibre jelly. However, during the manufacture of FIMT, as the filling rate increases so does the processing difficulty.

Hence the filling rate of FIMT should be controlled above 80% according to the level of tubing process ability. HMCS has an excellent manufacture ability to control the filling rate stable above 90% currently to achieve a better water ingress performance.

5.2 Improving the Water Ingress Performance of LW Core

The new two part compound water blocking glue, COMPOUND-A/B was trailed in HORC-1 LW. After completion of the composite conductor cable element, it was observed that the glue can effectively fill the gaps, provide effective adhesion to the steel wires and was evenly applied along the cable length. The test showed that COMPOUND-A/B has good processability and adhesion to the steel wires.

After the insulation extrusion process, the completed LW cable was allowed to stand for 2 days to ensure all the water blocking glue cured and then a sample was prepared for the water ingress performance evaluation.

5.2.1 Influence of Water Blocking Glue Filling Rate

COMPOUND-A/B belongs to sealed-filling type water blocking glue, so the filling rate of water blocking glue has a big influence on the water ingress performance. 5 different cables were manufactured in the same process condition but with different filling rates of COMPOUND-A/B. The water ingress performance was analyzed and compared for each sample. Each LW sample length was 500m and was tested at 20MPa for 14 days. The test results are shown in Figure 8.

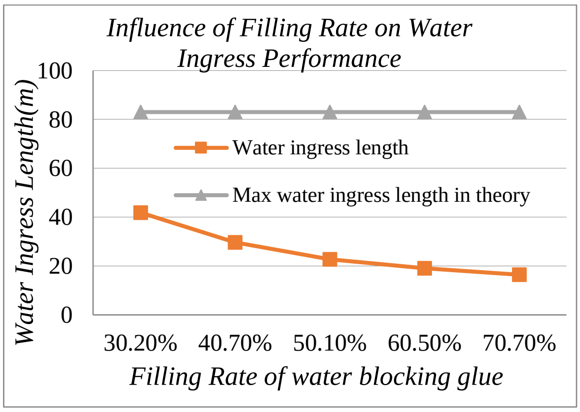

Figure 8: Influence of filling rate of water blocking glue on water ingress performance

The test results showed that, the water ingress performance can be improved by increasing filling rate of water blocking glue but the rate of improvement reduces when the filling rate exceeds 50%.

Therefore a 60% filling rate of water blocking glue was selected as the minimum standard for cable production to achieve the required performance.

5.2.2 Simulation Performance Evaluation

To evaluate the water ingress performance of submarine cable over a range of water depths, three HORC-1 LW cables each with a length of 500m were manufactured with the filling rate of COMPOUND-A/B controlled to 60%. Water ingress tests were carried out in 3 conditions: 200m (2MPa), 2000m (20MPa) and 5200m (52MPa) for 14 days.

Evaluation results are shown in Figure 9.

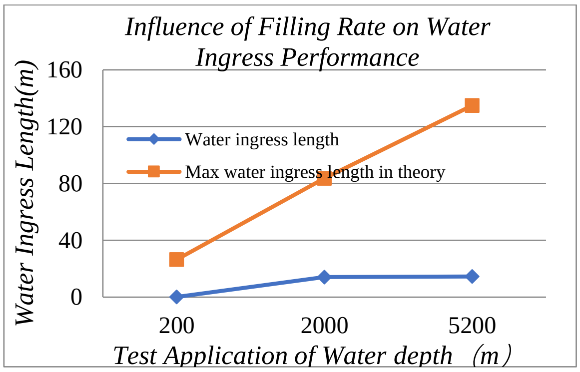

Figure 9: Water ingress performance evaluation in different water depth

The results showed that, we can control the water ingress performance of inner armour elements according to control filling rate of COMPOUND-A/B to 60%. This can satisfy the submarine cable requirement sufficiently.

6. SEA TRIAL VERIFICATION

HMCS organized an international sea trial operation lasting 30 days over the timeline from 2017.4.11 to 2017.5.10. Hengtong Marine HOUC-1 un-repeatered cable and HORC-1 repeatered cable products were integrated with HMN R1(2 fibre pair) repeaters & R2(6 fibre pair) repeaters together with Universal Joints & Universal Quick Joints.

SBSS was selected as the preferred marine operator and the CS Fu Hai was mobilized to Hengtong Port for the sea trial, equipped with a SMD MD3 cable burial plough capable of 2m to 3m burial into the seabed.

Figure 10: CS Fu Hai

Three sea trial locations were selected for the trials, generally lying to the South and South East of Japan, in an open exposed Pacific Ocean location.

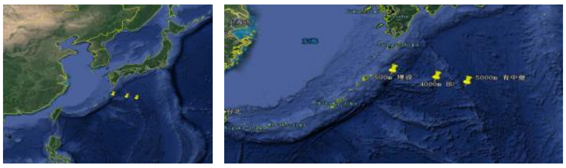

Figure 11: HMCS Sea Trial location

The water ingress performance trial was located in the area 28°01′N 134°58′E where the sea depth was 5200m. After recovery the HORC-1 LW cable water ingress sample was checked for water which was found to have ingressed 35m into the cable structure after 2 days, less than the maximum theoretical water ingress length of 50m. This confirms that HMCS HORC-1 LW cable has an excellent water ingress performance.

7. CONCLUSION

Since the development of submarine cable, the reliability of cables becomes more and more important, especially when considering the water ingress performance. Submarine cables designed and manufactured with good control over the axial water blocking characteristics are very important for the future maintenance if submarine cables are damaged by external forces. This paper researched the improvements from FIMT and inner armour water blocking aspects. Results showed that:

1. A suitable filling rate(≥80%) of fibre jelly can improve the water ingress performance

of FIMT effectively and meet cable design & process requirements.

2. A two component water blocking glue has been developed to fill into the inner armour wire gaps. When controlling the filling rate of water blocking glue to 60%, HORC-1 LW cable can achieve excellent water ingress performance and this has been successfully demonstrated during sea trials.