Return to Session

POLYMERIC ARMOR DESIGN OF AN IMPROVED PROTECTION TO MECHANICAL STRESSES AND FLUIDS FOR OIL GAS AND PETROCHEM (OGP) APPLICATIONS

Paul CINQUEMANI, Prysmian Cables & Systems USA, LLC, paul.cinquemani@prysmian.com
Luca DE RAI, Prysmian Cables & Systems SpA, (Italy), luca.derai@prysmian.com
Marco FRIGERIO, Prysmian Cables & Systems SpA, (Italy), marco.frigerio@prysmian.com
Paolo VEGGETTI, Prysmian Cables & Systems Oy, (Finland), paolo.veggetti@prysmian.com

ABSTRACT

Electric power cables for OGP application can be subjected to very high tension during installation, so they can get damaged by high Sidewall Bearing Pressure and by other accidental impacts. Typically, manufacturers and cable installers have used various ways to protect cables from mechanical stresses. Cable manufacturers use metal clad armor of either aluminum interlocked armor (AIA) or continuously corrugated metal armor. This paper will detail the development and evaluation of a new design of power cable that provides increased mechanical protection without the use of metallic armor while also improving overall flexibility, by a composite polymeric protection. The new design incorporates a polymer layer that has been shown to improve both the mechanical toughness of electrical power cables while providing improved flexibility compared to cables using metallic armor.

In addition, the cable design must be suitable to protect the insulated cores from the attack of hydrocarbons, oils and various fluids which are typical of the OGP industry applications. The design proposed is providing the necessary protection to fluids by a special polymeric layer, combined with a metal thin foil, without all the disadvantages of the metal clad armored cables (weight, stiffness, difficult termination etc.).

The data presented supports that polymeric armor provides 5 times better impact performance than metallic armored products, and provides a fluids protection equivalent to the metal clad armor design. This allows installers and customers to install cables for longer distances without the need for expensive splices which also affects cable reliability; the experience on the installation field by a few customers is already confirming the great benefits of such new cable.

INTRODUCTION

The NFPA National Electrical Code (NEC) clearly defines the applications where Metal Clad Cables (Type MC) are required to be installed or may optionally be used in the occupancies covered therein [1]. In many other locations and applications metal clad cable may be used as a beneficial option such as conduit replacement or as an alternate design when greater mechanical abuse resistant cable is desired by the end user.

In fact it has become quite common for multi-conductor Type MC power cables to be installed as the cable of choice in many industry applications, even where metal clad is not required by the NEC. The popularity arises from the diverse installations and locations where additional mechanical abuse resistance is beneficial to the end user. However, one major drawback to installation of conventional metal clad cables is the limitation of maximum lengths that can be pulled due to sidewall bearing pressure contraints.

Conventional Type MC encompasses basically two types 1) continuous corrugated aluminum sheath and 2) aluminum interlocked strip armor (AIA) that is also provided to a lesser extent with galvanized steel strips (GSIA).

The continuous corrugated aluminum sheath is typically produced by forming a flat aluminum sheath circumferentially and longitudinally around a cabled core whereas it is then slit to proper width, edge welded and lastly corrugated. The profiles of the corrugations are specifically designed to provide optimum bending characteristics. This design results in a very rigid armor with limited sidewall bearing pressure (SWBP) capabilities during installation. Industry recommendations vary between 1000 to 1500 pounds per foot of bend-radius.

The interlocked aluminum strip armor is typically produced with two (2) predetermined flat strips that are edge formed, shaped and helically applied in a single pass resulting in tape armor where each strip is interlocked with each adjacent strip. This armor results is a somewhat more flexible armor compared to the continuously corrugated aluminum. Due to the strip interlocking this armor lacks an impervious barrier and cannot protect the cable core against aggressive chemicals or moisture. This design is also further limited in SWBP to industry recommended values of 800 pounds per foot of bend-radius.

Return to Session

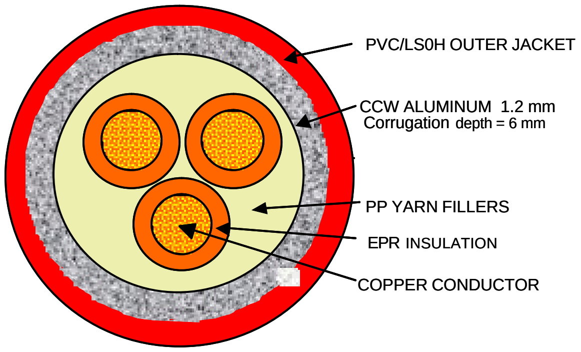


Figure 1. Conventional Type MC - Continuous Corrugated Aluminum Sheath Design

In both conventional Type MC designs, exceeding the maximum recommended values of SWBP during an installation may distort or tend to flatten the metal clad armor. This permanent change of shape can distort the underlying core resulting in excessive electrical stress within the insulated conductor as well other mechanical damages to the core. Extreme damage may result in immediate detection or cable failure during field testing prior to energizing the circuit. Lesser damage may go undetected, ultimately leading premature electrical failure in service.

POLYMERIC SHIELD FOR MECHANICAL AND CHEMICAL PROTECTION

New concepts to mechanical protection have led to the development of advanced polymeric armor designs that provide the essential mechanical armor characteristics as well as protection against moisture and chemicals. Polymeric armor designs consist of multiple layers as shown in Figure 2.

.

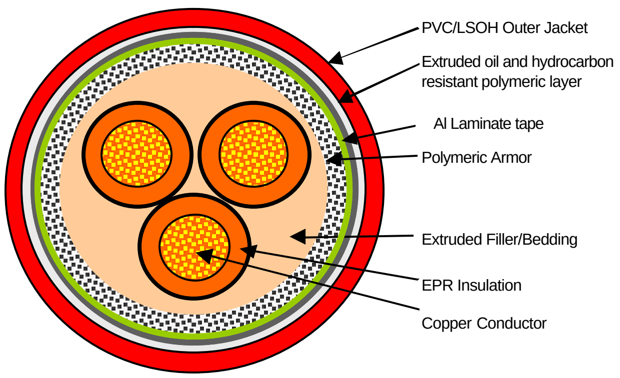


Figure 2. Polymeric shield design

The components consist of the following:
Filler/Bedding: Extruded halogen free non-hydroscopic polymeric bedding or optional non-hydroscopic filler yarns.
Polymeric Protection: Impact resistant, shock absorbing extruded polymer capable of reducing risk of permanent deformation and damage to the underlying core.
Metallic Shield: Copolymer coated aluminum tape longitudinally applied with sealed overlap.
Polymeric Layer: Extruded layer bonded to the underlying metallic shield barrier. This combination is resistant to aggressive chemicals such as hydrocarbons, solvents, acids, bases and moisture.
Sheath: Extruded overall low temperature, flame and sunlight resistant polyvinyl chloride or low smoke halogen free jacket.

PERFORMANCE OF POLYMERIC SHIELD

Impact Performance

Comparative impact testing was conducted in apparatus designed in accordance with EDF Specification HN 33-S-52 [5]. The test was conducted at different energy impact levels and employed an impact tool of a 90° V shaped wedge with 80 mils (2 mm) radius tip. After a single impact at the specified energy level, the thicknesses of various layers and local damage on the extruded insulation shield, by means of an optical laser system, was measured with an electronic digital caliber.

Mass	Height of Weight	Energy of Impact	Damage on Insulation
(N)	inches (mm)	(Joules)	mils (mm)
550	14.3 (363.6)	200	26 (0.65)
	17.9 (454.4)	250	28 (0.7)
	21.5 (545.4)	300	28 (0.7)

Table 1. Impact Test Results on 3/C #2/0 AWG – 15 kV Rated Cable with Polymeric Armor

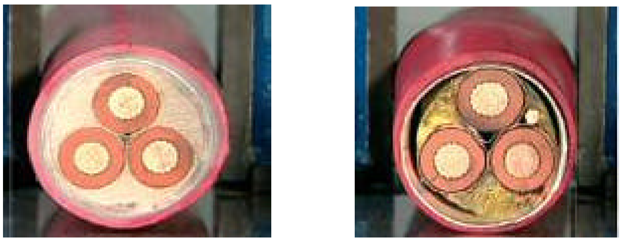
Mass	Height	Energy of Impact	Damage on Insulation
(N)	(mm)	(Joules)	mils (mm)
550	14.3 (363.6)	200	95 (2.4)
	17.9 (454.5)	250	98 (2.5)
	21.5 (545.4)	300	110 (2.8)

Table 2. Impact Test Results on 3/C #2/0 AWG – 15 kV Rated Cable with Continuous Corrugated Armor

Testing continued on the three conductor 2/0 AWG 15kV rated cables employing polymeric armour and continuous corrugated aluminium armor to determine the magnitude of impact on each design that resulted in the same level of damage on the ethylene propylene rubber (EPR) insulated conductor. This was determined to be an impact level of 200 joules for the polymeric armour design as compared to 140 joules for the continuous & corrugated aluminium metal clad cable design.

Further testing on three conductor 350 kcm 15 kV rated cables found the impact magnitude that resulted in the equivalent level damage on the insulation shield of the EPR insulated conductor was 250 joules for the polymeric armour and 200 joules for the continuous & corrugated aluminium metal clad cable design.

Return to Session



Polymeric Armor — Continuous Corrugated Aluminum Armor

Figure 3. Polymeric Armor and Continuous Corrugated Al Armor - 3/C 350 kcm 15 kV - Before Impact Testing

Polymeric Armor — Continuous Corrugated Aluminum Armor

Figure 4. Polymeric Armor and Continuous Corrugated Al Armor - 3/C 350 kcm 15 KV - After 250 Joules of Impact

Impact testing was also conducted on typical 600 volt rated control cables. The typical cable configuration of nine (9) conductors #12 AWG conductor cables was employed The testing apparatus and impact tool design were identical as employed for impact testing of the 15 kV power cable sizes.

Mass (N)	Height of Weight inches (mm)	Energy of Impact (Joule)	Damage on Insulated delta diameter, mils (mm)
250	4.7 (120.0)	30	**8 (0.2)**
250	6.3 (160.0)	40	8 (0.2)
250	7.9 (200.0)	50	11.8 (0.3)
250	9.5 (240.0)	60	21.7 (0.55)
250	11.0 (280.0)	70	25.6 (0.65)
250	12.6 (320.0)	80	**27.6 (0.7)**

Table 3. Impact Test Results on 9/C #12 AWG – 600 V Rated Power Control with Polymeric Armor

Mass (N)	Height of Weight (mm)	Energy of Impact (Joule)	Damage on Insulated delta diameter, mils (mm)
250	4.7 (120.0)	30	**31.5 (0.8)**
250	6.3 (160.0)	40	**31.5 (0.8)**
250	7.9 (200.0)	50	**31.5 (0.8)**
250	9.5 (240.0)	60	35.4 (0.9)
250	11.0 (280.0)	70	43.3 (1.1)
250	12.6 (320.0)	80	**57.1 (1.45)**

Table 4. Impact Test Results on 9/C #12 AWG – 600 V Rated Control with Continuous Corrugated Armor

This technology has also been adopted in communications and optical fiber cable designs for terrestrial and aerial applications replacing metallic armor/sheaths as successfully demonstrated in power and control cables.

Figure 5. Polymeric Armor and Continuous Corrugated Al Armor – 9/C #12 AWG 600 V Cables - After 80 Joules of Impact and Overall Jacket Removed

Figure 6. 9/C #12 AWG Insulated Core Removed From Polymeric Armor Design After 80 Joules Impact

Figure 7. 9/C #12 AWG Insulated Core Removed From Continuous Corrugated Al Armor - 80 Joules Impact

The severity of an 80 joules impact can easily be seen in Figure 5. At this impact level the measured damage on the insulated core is two times greater on the continuous corrugated aluminum armor than the polymeric armor. This can be seen in Figure 7 where exposure of the #12 AWG conductors through the insulation was observed. The criticality of such exposure is the potential to lose circuit integrity via phase to phase or phase to armor and potentially short circuiting and losing power to critical equipment and instrumentation in an industrial or commercial facility. The insulation within the core of the polymeric armor cable, while exhibiting some damage is not in jeopardy of a phase to phase short circuit.

Sidewall Bearing Pressure Performance

Sidewall Bearing Pressure (SWBP) develops when a cable is pulled around a bend under pulling tension. It is the vector sum of the sidewall pressure due to tension in the conductor acting horizontally, and the weight of the conductor acting vertically. SWBP should always be calculated for that conductor that presses hardest on the inside bend of the curvature, i.e., pipe, conduct, wheel, etc.

In most cases sidewall bearing pressure limits for power

Return to Session

cable have been demonstrated to be quite satisfactory via 30 to 50 years of historical data. These were initially based upon theoretical methods and consequently, safety factors were incorporated in the equations. Currently, North American standards do not define a test protocol for determination of sidewall bearing pressure. Recent work has been conducted to prove the electrical and mechanical suitability in reducing insulation thickness for medium voltage cables. Specifically SWBP test apparatus was developed and implemented to demonstrate that such cables can withstand the SWBP rigors of standard full wall cables for the same voltage classes. However, the apparatus for this work was limited to single conductor cables and was intended to demonstrate the suitability at currently accepted SWBP limits. In earlier work under the Electric Power Research Institute (EPRI) testing methodologies were developed for this program but were greatly focused on single core electrical utility type cables. Both of these methods were independently developed due to no recognized standardization for such as test. For this project in consideration that multi-conductor power cables were quite large, the SWBP testing was conducted in accordance IEC Draft 901TR ED.1 Clause 5.2, intended for larger core cable.

.

Figure 8. Apparatus for Sidewall Bearing Pressure Testing

Here a 50 foot (15 m) length of cable is passed forwards and backwards around a fixed wheel under a SWBP calculated by T/R using the tension of the steel wire (T) from the pulling wench and the wheel radius (R). The cable remains in contact with the fixed wheel for at least 90° during the test. Lubricant may be applied as necessary at the contact point of the wheel. Repeated testing of medium voltage designs of polymeric armor cables has resulted in a maximum recommended sidewall bearing pressure of 3000 pounds per foot of bend-radius. This is twice the industry maximum value of 1500 pounds for corrugated and welded armor.

Installation Performance

In a recent actual installation, three conductor 350 kcm and three conductor 750 kcm copper 15 kV rated cables with polymeric armor were installed in a very tortuous cable route. Typically when power cables are installed pulling tensions, bending radius and sidewall bearing pressures are monitored. Once the sidewall bearing pressure has reached the maximum limit the installer can utilize a mid-assist/tugger device to reduce the tension seen at the pulling eye or grip. This lowers the SWBP so the cables can continue to be pulled without damage to the cable core. In severe cases where mid-assisting may not be sufficient and the installation profile cannot be changed to reduce tension, the cable must be cut and spliced. This is undesirable as splices in such pulling profiles can be difficult to accomplish in tight quarters, will result in lost time and increased installation costs, and provide an opportunity to reduce integrity of the electrical system over the life of the cable.

With a maximum allowable SWPB limit of 3000 pound/ft both polymeric armored cables were successfully installed in this demanding pull. Even the 750 kcm 15 kV rated cable did not show any signs of damage with SWBP measured and exceeding 2000 pounds/ft.

Several times during the installation the SWPB exceeded 1500 pounds/ft which is the maximum limit for continuous corrugated armor. If 3/C 750 kcm cables with continuous corrugated armor were employed for this installation, two splice points would have been required to avoid damage to the cable.

Chemical protection performance

In order to evaluate the chemical performance of the polymeric shield design, the cable has been submitted to different kind of tests.

The specifications UL1072 for MV cables and UL44 for LV cables require the “Fuel C” and “Oil IRM902” test compliancy of the complete cable.

The purpose of the tests is to measure the performance of the cable versus aggressive fluids at high temperature, which are present in OGP and chemical industry applications.

After the cable has been exposed to such fluids for a long period, the insulation characteristics have been measured, in order to assess indirectly the permeability of the polymeric shield and the effects on the electrical performances of the insulated cores.

Fuel C test

Material: aromatic fuel

Characteristics:

- Low vapour pressure
- Low viscosity/molecular weight => high permeation rate
- Highly aggressive against rubber (as by ASTM D471)
- Widely used in chemical industry

Measurements:

- Density
- Mechanical properties (insulation)

Return to Session

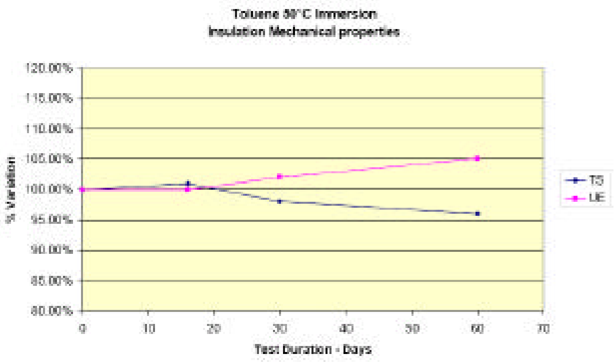


Figure 9. Toluene 50°C immersion – insulation mechanical properties

In addition, a numerical calculation has been done to estimate the long term permeation values of toluene at 25°C and 50°C; such calculation is based on the permeability measurement on the complete cable.
The results in figure 10 show the hydrocarbon concentration on the unprotected conventional design versus the polymeric shield design, extended to 10 years period. The safe level line is the limit within the cable operational is not affected.

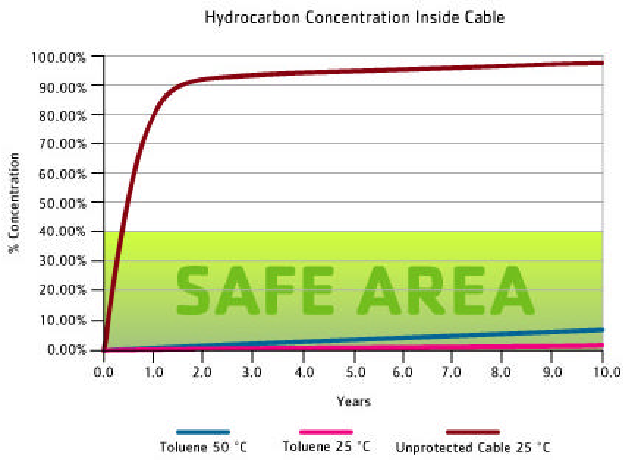


Figure 10. Hydrocarbon concentration inside cable

Oil IRM902 test
Material: highly parafinic oil
Characteristics:
- o Most commonly used reference oil in chemical industry
- o Higher viscosity/molecular weight
- o Aggressive against plastics

Measurements:
- o Density
- o Mechanical properties (insulation)

Figure 11. Oil immersion of cable in oven

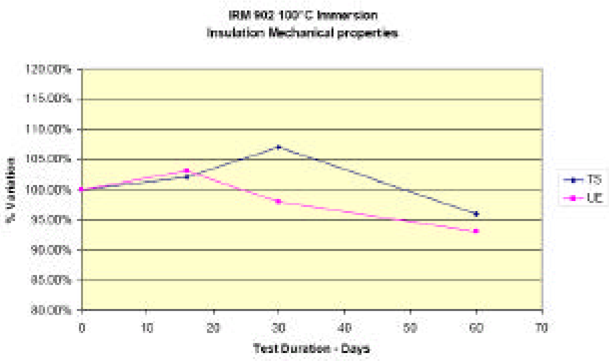


Figure 12. IRM902 100°C immersion – insulation mechanical properties

Return to Session

CONCLUSIONS

Direct comparison testing between new advanced polymeric shield designs and continuous corrugated aluminum armor designs have been conducted. Polymer armor designs have shown to be significantly more resistant to crush and impact type damage and able to withstand much higher lateral forces during installation. In addition, cable testing versus aggressive fluids has been assessed: the polymeric shield design is providing long term high resistance to oil and hydrocarbons at high temperature.

Such polymeric shield designs have also been subjected to and passed an extreme battery of flame propagation testing, smoke testing, cold bend/impact at testing -40°C and are approved under the auspices of Underwriters Laboratories, Canadian Standards Association, American Bureau of Shipping, Coast Guard, etc.

Figure 13. Cutback of 3/C Medium Voltage Polymeric Armor Design

REFERENCES

[1] NFPA 70: National Fire Protection Association, "National Electrical Code , 2005

[2] HN 33-S-52 EDF Specification for "Single Core Cables with Polymeric Insulation for Rated Voltages of 36/63 (72.5) kV and 52/90 (100) kV and up to 87/150 (170) kV".

[3] Y. Wen and P. Cinquemani, "Performance of Reduced Wall EPR Insulated Medium Voltage Power Cables: Part II Mechanical Characteristics, *IEEE-PES Transmission & Distribution Conference, 1996.*

[4] EPRI-EL-3333, "Maximum Safe Pulling Lengths for Solid Dielectric Insulated Cables, Volumes 1 and 2, February 1984

[5] IEC Draft 61901TR ED.1 - 20/682/CD Clause 5.2, "Development Tests Recommended on Cables with a Longitudinally Applied Metal Tape, April 2004