Development and characterisation of metallic sheaths for sustainable submarine power cables

Chiara **BARCELLINI**, Enrico **CAZZULO**, Federico **CORDÒ**, Marina **GANDINI**, Enrico **CONSONNI**; Prysmian Group, (Italy), chiara,barcellini@prysmiangroup.com, enrico.cazzulo@prysmiangroup.com, federico.cordo@prysmiangroup.com, marina.gandini@prysmiangroup.com, enrico.consonni@prysmiangroup.com

ABSTRACT

The need to find an alternative solution to lead as hermetic metallic sheath material for submarine high voltage cables urges for additional studies on possible laminated metallic coverings. One of the most suitable candidates to replace lead is represented by copper and its alloys. The progresses made in this field of research are here presented. A full mechanical and microscopical characterisation is performed aiming to link the mechanical performances with the geometrical parameters and the microstructure of the laminated products. Welding and soldering solutions available are also discussed in relation with mechanical properties and water tightness.

KEYWORDS

Submarine cables, high voltages, metallic sheath, copper, copper alloys, optical microscopy.

INTRODCUTION

In high voltage cables, due to the high electric stress experienced by the insulating materials, it is of paramount importance to guarantee for the whole system lifetime the avoidance of water ingression and humidity diffusion in both mass impregnated (MI) and extruded insulation technologies. For this reason, a continuous metallic water-blocking sheath is applied over the cable insulation [1] [2] . This layer also plays a role in creating a conductive pattern for circulating, capacitive and short circuit currents [1].

Since the first development of submarine cables, extruded lead was the selected solution as water barrier and electrical screen. It was chosen mainly for the low melting temperature, which makes this metal suitable for continuous extrusion on cables [3] [4] . It also has an excellent corrosion resistance and high workability. Lead, however, has a very high specific weight and poor performances in case of dynamic mechanical load application. Being subject to fatigue failures, with the formation of microcracks which deteriorate its water tightness, lead cannot be employed for the manufacturing of dynamic cables for floating wind farms.

Many studies to identify alternative solutions to lead are currently in progress based on the specific application, as also highlighted by CIGRE TB 446 [5] , The most suitable candidate to substitute lead for high voltages submarine cables is represented by copper [6] . The advantages of this metal include excellent corrosion and fatigue resistance, easy welding and soldering and compliance with sustainability trends. Laminated copper sheaths are lighter than extruded lead sheath, allowing a diameter reduction and guaranteeing longer campaigns thus decreasing both the amount of joints, with consequent possible cost reductions, and the greenhouse gas emissions.

The progresses in this field of research are here presented. Sheaths manufactured with different copper grades are discussed. A full mechanical and microscopical characterisation is performed aiming to link the mechanical performances with the geometrical parameters and the microstructure of the laminated products. Welding and soldering solutions available are also discussed in relation with mechanical properties. The possibility of substituting copper with one of its alloys is also explored.

Copper and Copper alloys general characteristics

Copper and most of its alloys have a face-cantered cubic (FCC) crystal structure and high electrical and thermal conductivity, lower only to those of gold and silver. It possesses also high level of ductility, toughness, and formability, which make it suitable to produce thin sheets and wires. It is widely used in the marine industry due to its very good resistance to corrosion in various aqueous environments. Annealed copper has good mechanical properties: a tensile strength (R_m) between 180 and 220 MPa, a yield strength ($R_{p0.2\%}$) between 80 and 120 MPa and an elongation at break (**A_t**) beyond 40% [7]. Physical and mechanical properties can be refined with cold working and annealing to manipulate microstructure. While great for conducting electricity and heat, pure copper is so ductile that it is difficult to machine. Alloying is an effective way to increase strength.

In the submarine cable industry, copper is a common choice for both the conductor and the metallic sheath. For the first cable component, the grade of choice is high purity copper because of its very low electrical resistivity. Electrolytic Tough Pitch (ETP) copper is the most popular grade for cable cores and is 99.90% pure. For the latter, the choice might both pure copper and copper alloys, depending on the application. Copper alloys are designated according to the Copper Development Association (CDA) and fall into two major categories: wrought and cast alloys. Notable wrought alloys are brass (Cu-Zn), bronze (Cu-Sn), and cupronickel (Cu-Ni). Dilute Cu alloys have low alloy content, with common additions being Ag, Cd, As, Pb, Te, Sb, and Se. High-copper alloys have between 96% and 99.3% Cu [8] . Copper grades of interest for metallic sheaths include aluminium bronzes, tin bronzes, and cupronickel. Al bronzes have excellent corrosion resistance due to the formation of a self-healing surface film of aluminium oxide. A small addition of As can further help by preventing dezincification. Tin bronzes are stronger and have better corrosion resistance properties than brasses, especially in their cold-corked conditions. Cu-Ni alloys offer high resistance to both corrosion and fatigue while retaining ductility due to their substitutional solid solution FCC structure. Between 23 wt% to 27 wt% nickel gives the most desirable properties for welding and fatigue resistance, while keeping costs of nickel down, along with the addition of Si, Mn, and Fe to improve fatigue strength [9].