4.4.2 Physics of conductor strength

Conductors derive their strength from the metallurgical properties of the parent metal and from cold working the strands during the rolling and/or drawing process used to shape the strands. This cold working enhances the strand's tensile strength by stretching and locking up atomic grain boundaries and atomic lattices. For example, the process of cold working pure aluminum (1350 alloy) produces about 70% of the strand's overall strength.

4.4.3 High-temperature effects on conductor strength

Loss in conductor strength is the result of annealing in the aluminum or copper strands by relaxing the mechanical stress in the grain boundaries and lattices achieved during cold working. The extent of this loss is a function of the material's composition, its operating temperature, the accumulated length of time at this operating temperature, and may also depend on conductor tension for copper. The aluminum begins to lose strength when operated above 93 °C. Copper loses strength with high-temperature operation beginning at about 75 °C. Note that the loss of strength of copper can be variable from one type of copper material to another. For effects of temperature and tension on the annealing of copper, see Hickernell et al. (1949). The strength of a conductor's steel core is not affected by temperatures below 200 °C.

4.4.4 Annealing effects on modulus of elasticity

As noted, aluminum and copper strands lose strength by annealing, which usually does not have a large effect on the final modulus of elasticity of all-aluminum or copper conductors. However, for highly annealed composite conductors, this loss in strength under heavy mechanical loads (i.e., ice) can permanently shift a large percentage of the tensile load from the aluminum strands onto the steel core. This redistribution of load causes extra conductor elongation, hence, greater sags than originally designed.

4.4.5 Predictor equations

Predictor equations for conductor loss of strength tend to simplify a complex phenomenon. Most predictor equations acknowledge the time and temperature dependence of strength loss, but they are still an empirical aggregate of several processes occurring simultaneously. Such equations should be limited to assisting the engineer in understanding some of the impacts of high-temperature operation on conductors and providing general quantitative predictions of strength loss. Annex C contains one method for calculating the remaining strength of a conductor as a percentage of its initial strength [see Harvey (1972)]. Other techniques are also available and should be investigated to determine which approach best suits anticipated applications [see Morgan (1995)].

4.5 High-temperature effects on conductor core

4.5.1 Introduction to steel core

Composite conductors (i.e., ACSR, AACSR, etc.) are stranded aluminum conductors reinforced with strands of steel wires to increase conductor strength.

The core wires of ACSR may be zinc-coated steel (galvanized) available in various strand weight thicknesses (Class A, B, or C), zinc-5% aluminum-mischmetal alloy-coated steel core wire, aluminum coated steel (aluminized), or aluminum-clad steel strands. Galvanized or aluminized coatings are applied to reduce corrosion of the steel wires. Aluminum clad strands have a greater aluminum thickness for increased conductance and greater corrosion protection than aluminized strands. They also provide an aluminum-to-aluminum contact between the core and outer aluminum wires to prevent the possibility of galvanic corrosion.

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4.5.2 High-temperature effects on galvanized steel core

Laboratory investigations have shown that high-temperature operation of conductors with a galvanized steel core can be limited by the adherence of zinc coating to steel core wires. Some important generalizations and observations about high-temperature operation of galvanized steel core wire are as follows:

— The steel strands of ACSR conductors will run hotter than the aluminum strands. Tests show temperature gradients between the steel core and outer aluminum strands can be as high as 10% of the conductor surface temperature for new conductors and 20% for old conductors, depending on stranding, age, and ambient conditions.

— The zinc coating does not adhere well to the core wires at temperatures in excess of 200 °C. Operating temperatures above this value will decrease the life expectancy of in-service conductors because of reduced corrosion resistance from subsequent pitting of the steel strands.

— Temperatures in excess of 300 °C cause the zinc surface layer to alloy with the underlying steel. This alloying forms brittle compounds that have a tendency to flake and spall; plus they also tend to lower the corrosion resistance of the galvanized wire. Additionally, brittle cracks in the zinc alloy layer will greatly increase the underlying steel's susceptibility to fatigue. Such temperatures cause a reduction in steel hardness and tensile strength.

4.5.3 High-temperature effects on aluminum-clad core

The mechanical characteristics of an aluminum-clad core are similar to those of a steel core because of their comparable steel-strength-to-total-core-strength ratios (approximately 0.94). High-temperature effects on aluminum-clad strands are minimal up to approximately 325 °C. Above such temperatures, the tensile strength of these strands exhibit a smooth degradation with temperature.

4.6 High-temperature effects on sags and tensions

4.6.1 Introduction to conductor sag-tension models

A conductor will elongate both elastically and nonelastically because of changes in temperature and tension. At a constant temperature and within the elastic limit of a material, a uniform material will increase in length at a linear rate with increases in tension. Composite conductors made of materials having different modulus of elasticities, such as steel-reinforced conductors, will exhibit more complex sag-tension characteristics. As tension increases on composite conductors, the tension supported by each material will increase at a varying rate. The overall effect of this process is a nonuniform distribution of mechanical load between the two materials with changing tension. In steel-reinforced conductors, the percentage of load supported by the steel core increases as conductor temperature increases.

4.6.2 High-temperature effects on sags and tensions

As discussed in 4.3, high-temperature operation of conductors can increase the amount of creep they experience. As conductor materials creep, conductor tensions decrease and sags increase. Some types of conductors are more affected by high-temperature operation than are others. Steel-reinforced conductors (ACSR, AACSR, ACSS) and copper conductors (Cu) are affected less by elevated temperature creep than are all-aluminum conductors (AAC, AAAC, ACAR). The increase in sag can result in electrical clearance problems to ground or other objects below the conductors. It is, therefore, important to predict the effect of high-temperature operation on conductor sag.

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