Aluminum vs. Copper: Conductors in Low Voltage Dry Type Transformers

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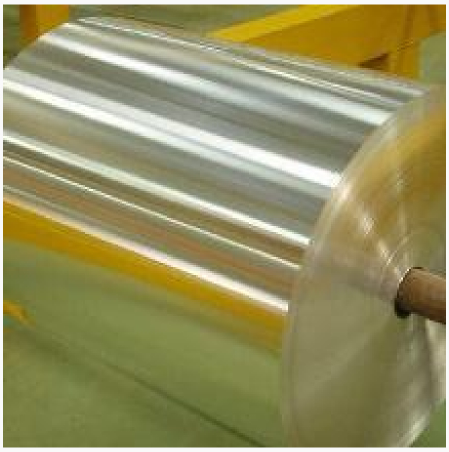
Predominant choice of winding material

In North America, aluminum is the predominant choice of winding material for low-voltage, dry-type transformers larger than 15 kilovolt-amperes(kVA). In most other areas of the world, copper is the predominant winding material. The primary reason for choosing aluminum windings is its lower initial cost.

The cost of copper base metal has historically proven to be much more volatile than the cost of aluminum, so that the purchase price of copper conductor generally is the most expensive choice. Also, because aluminum has greater malleability and is easier to weld, it is the lower-cost manufacturing choice. However, reliable aluminum connections require more discipline and expertise on the part of transformer installers than that needed for copper connections.



Aluminum-Strip-for-Electrical-Transformers-Winding

Technical arguments about the pros and cons of aluminum vs. copper have been traded back and forth in the electrical industry for many years. Most of these arguments are inconsequential and some can be classified simply as misinformation. The purpose of this Application Brief is to discuss some common concerns regarding the choice between these two winding materials.

Common Reasons for Winding Material Choice

Table 1	True	False
Aluminum-wound transformer terminations are incompatible with copper line and load cables.		X
Properly terminating line and load connections is more difficult for aluminum-wound transformers.	X	
Line and load connections to copper-wound transformers are more reliable than those to aluminum-wound transformers.		X
Aluminum wound transformers are lighter in weight than copper wound equivalents.	X	
Copper-wound low voltage transformers are better for “high-impact” loads because copper has higher tensile strength than aluminum.		X
Aluminum-wound transformers have higher losses because copper is a better conductor.		X
Aluminum-wound transformers have higher hot-spot temperatures because copper is a better thermal conductor than aluminum.		X

Differences Between Copper and Aluminum

Most concerns about winding material choice reflect five characteristic differences between copper and aluminum:

Five Characteristic Differences Between Cu and Al	Aluminum	Copper
Coefficient of Expansion per °C x 10^{-6} at 20°C	23	16.6
Thermal Conductivity BTU/ft/hr/fft^2/°F at 20°C	126	222
Electrical Conductivity %IAS at 20°C	61	101
Tensile Strength ib/in^2 (soft)	12,000	32,000

Connectivity

Oxides, chlorides, or sulfides of the base metal are much more conductive for copper than aluminum. This fact makes cleaning and protecting the joints for aluminum connections more important. Some consider copper-to-aluminum connections incompatible. Also questionable are the transition connections between aluminum transformers and copper building wire.

Coefficient of Expansion

Aluminum expands nearly one third more than copper under changing temperatures. This expansion, along with the ductile nature of aluminum, has caused some problems when bolted connections are improperly installed.

To avoid joint loosening, some type of spring pressure connection is necessary. Using either cupped or split washers provides the necessary elasticity at the joint without compressing the aluminum.

By using proper hardware, aluminum joints can be equal in quality to copper joints.

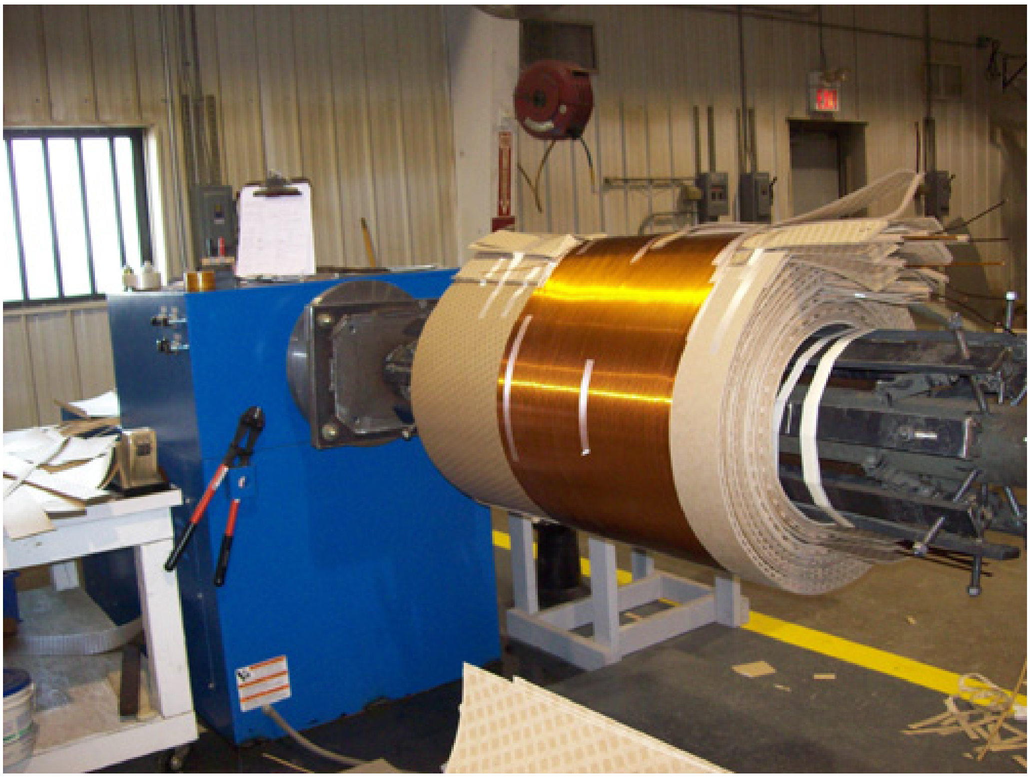
Thermal Conductivity

Some argue that the thermal conductivity of copper is superior to that of aluminum in reducing hot-spot temperature rise in transformer windings. This is true only when copper and aluminum windings of identical wire size, geometry, and design are compared. Therefore, for any given transformer kVA size, the thermal conductivity characteristics of aluminum can be very close to those of copper. For aluminum coils to achieve the same current-carrying capacity as copper, the aluminum coil must be approximately 66% larger in its cross-sectional area. Responsible manufacturers design and test the hot-spot characteristics of their designs and utilize cooling surface area, coil geometry, air ducting, and conductor shape to produce acceptable hot-spot gradients regardless of winding material.

Electrical Conductivity

Often, arguments point to the inferiority of aluminum conductivity, citing the fact that aluminum has only 61% of the conductivity of copper, which causes higher energy losses in aluminum transformers. Designers are always concerned with winding temperature. To keep the temperature below the insulation rating, aluminum transformers are designed with aluminum conductors of larger cross-sectional area than copper. On average, this results in energy losses that are the same for aluminum as for copper. Therefore, transformers of similar design with the same temperature rise have roughly equivalent losses regardless of conductor material.

Transformer manufacturers limit the variety of conductor sizes stocked. Because of this, some designs in aluminum can obtain lower losses than copper simply because the choice of wire size is limited. In other designs, copper is more efficient. Few, if any, low voltage dry-type transformer manufacturers change frame size of the core when switching from aluminum to copper, so core loss remains roughly equivalent regardless of the winding material. If equal efficiency can be obtained by varying the wire size and core losses remain the same, there is no practical reason to expect one design to be more efficient than the other. The cost differential between copper and aluminum can often make it possible to provide larger aluminum conductors, which results in lower load losses at less cost than if copper conductors were used.



Tensile Strength

The lower tensile and yield strength of aluminum has prompted some concern about its use in cyclic load applications. Loads drawing high peaks of current such as DC drives and other SCR controllers, create electromagnetic forces that can cause movement of conductors and coil leads. As shown in Table 2, aluminum has only 38% of the tensile strength of copper. However, the table comparison is based on equal cross-sectional area. As previously noted, to obtain equal ratings in aluminum transformers, it typically requires 66% more cross-sectional area than copper conductors. The use of larger-sized conductors results in aluminum winding strength nearly equivalent to copper windings. The ability of a transformer to withstand the long-term mechanical effects of “high impact” loads depends more on adequate coil balance and lead support than on conductor choice. No significant difference in mechanical failure has been experienced between copper or aluminum low voltage transformers.

Connectivity

Connectivity is by far the most common reason for “prejudice” against the use of aluminum-wound transformers. Both copper and aluminum are prone to oxidation or other chemical changes when exposed to the atmosphere. The problem is that aluminum oxide is a very good insulator, whereas copper oxide, although not considered to be a good conductor, is not nearly as troublesome in bolted connections. Cleaning and brushing with a quality joint compound to prevent oxidation is recommended for either material and simply more essential for aluminum. Most electricians are well trained in these procedures, and the technique of making bolted aluminum connections is a well-established and proven practice.

In general, bolted connection of unplated aluminum to copper is discouraged. Although several reliable welding processes and explosive bonding techniques can be performed to join the two metals, neither are used to a great degree in present transformer manufacturing. The majority of aluminum-to-copper connections are made by applying silver-or tin-plating to either or both of the conductor metals in the bolted connection. The majority of cable connections to aluminum-wound transformers use tin-plated aluminum lugs. These lugs are specifically rated (Al/Cu) for connecting copper building wire to either metal. This practice is universally accepted and has proven to be reliable throughout the more than 30 years aluminum -wound transformers have been in use.

Theory vs. Practical Use

Most arguments in favor of copper have been based on theories which, in practice, amount to nothing substantial. Several theories also exist that favor the use of aluminum.

One argument focuses on the different techniques used to make copper and aluminum connections. Internal transformer connections made with copper are generally brazed, whereas the same aluminum connections are welded using inert gas. Technically, the brazing technique causes the copper connection to have lower conductivity than the copper base metal. Inert gas welding of aluminum produces a continuous aluminum joint with no degradation of conductivity. In addition, some argue that over time copper oxide continues to form, flaking off exposed copper and eventually damaging the entire conductor. On the other hand, aluminum oxide forms a tenacious, protective coat over the exposed metal, which stops the oxidation after only a few millionths of an inch. Yes, these may be valid points that may have an impact in unusually corrosive atmospheres or extreme conditions of loading. However, the average user should really not be too concerned about these theoretical considerations because both copper and aluminum transformers have excellent records in long years of practical use.

The only valid engineering reason for choosing copper over aluminum appears to be space considerations. An irrefutable fact is that copper-wound transformer can be made smaller than aluminum transformers. Mainly OEM customers, who purchase open-core-and-coil transformers to put into their own devices, take advantage of the space savings. Most enclosed general purpose transformers are sold in the same enclosure size for aluminum or copper, so that even this small advantage for copper is not realized.

Conclusion

Choosing between aluminum or copper transformer windings comes down to personal preference. The premium price for copper often requires purchase justification, but these arguments have been refuted in this bulletin. In truth, industry experience simply does not support any of the commonly stated reasons for choosing copper over aluminum. Aluminum-wound low voltage transformers will probably continue to gain increased acceptance because of their significant cost advantage over copper.

As some of the old myths disappear because of the overwhelming success of the aluminum, more users will become comfortable with the relatively minor additional attention to detail necessary for making reliable aluminum connections. The extra attention given to aluminum joints has been theorized to contribute to *better* joints in aluminum than in copper.

However, good practices when making electrical connections are an advantage to everyone in the industry, regardless of whether aluminum or copper is being used. Before investing in the additional cost of copper transformers, examine the reasons for copper preferences in the specifications.